Research Problem Review 78-28

LEVEL II

BEHAVIORAL AND FUNCTIONAL REQUIREMENTS FOR A VISUAL FLIGHT RESEARCH FACILITY

HUMAN FACTORS IN TACTICAL OPERATIONS TECHNICAL AREA

U. S. Army
Research Institute for the Behavioral and Social Sciences

September 1978

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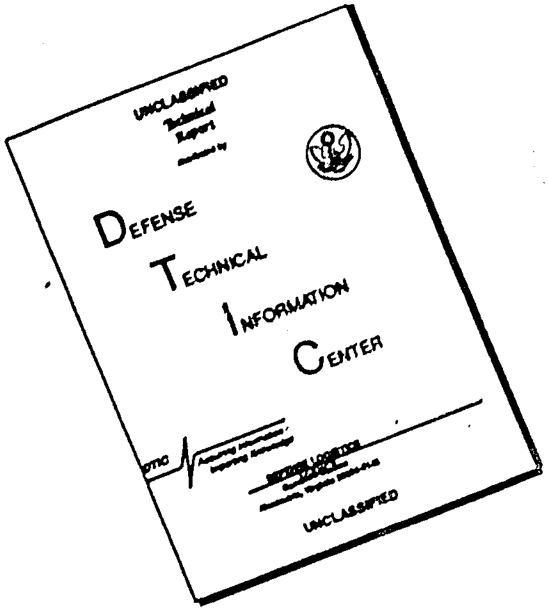

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NOTICES

Army Project Number
16 2Q162106A723

Aircrew Performance

14

ARI- Research Problem Review-78-28

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BEHAVIORAL AND FUNCTIONAL REQUIREMENTS FOR A VISUAL FLIGHT RESEARCH FACILITY

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FOREWORD

One of the long-range programs of the Army Research Institute for the Behavioral and Social Sciences (ARI) is designed to improve the selection, training, and performance evaluation of Army aviators. Flight at nap-of-the-earth altitudes poses unique visual and training problems. This report investigates requirements for a behavioral science research facility in this area and the evaluation of equipment alternatives to meet these requirements. As such, it presents a definitive methodology for establishing behavioral and performance requirements for design of a research facility.

Work was done in the Human Factors in Tactical Operations Technical Area of ARI, under Army project 2Q162106A723 (FY 74). Portions of the report draw upon work done under a related effort by Martin Marietta Aerospace under Contract DAHC19-74-C-0065. Current research in aircrew selection, training, and performance is carried out at the ARI Field Unit at Fort Rucker, Ala.

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BEHAVIORAL AND FUNCTIONAL REQUIREMENTS FOR A VISUAL FLIGHT RESEARCH FACILITY

BRIEF

Requirement:

Nap-of-the-Earth (NOE) flight is highly dependent on visual flight reference (VFR) and involves perceptual and behavioral problems in aircraft operation in such areas as visual discrimination of terrain features, judgment of depth and distance, geographical orientation, limited reaction time for obstacle avoidance, and performance under high workload. The problems become even more severe under conditions of poor visibility. In addition, the pilot must be able to maintain orientation between his displays and the real-world scene when he makes the transition from one mode of viewing to the other.

Consequently, the safety and survivability of helicopter flight at NOE altitudes depends directly upon the adequacy of the pilot's perceptual and behavioral responses and the degree to which they can be augmented and improved by visual aids and new operating procedures. Comprehensive behavioral research is needed to investigate such considerations as a pilot's basic perceptual capabilities under varying altitude and illumination conditions, visual requirements for new display aids, new flight procedures, improved decision and response time, work-sharing and coordinated crew activities, and techniques for improved navigation capability. A highly specialized flight research facility would be able to conduct effective NOE studies without concern for the safety considerations and the difficulty of experimental control inherent in conducting effective NOE studies in the field. Such a facility must meet the psychophysical and psychological requirements for behavioral research, including comprehensive performance assessment techniques.

Procedure:

A proposed helicopter research program served as the frame of reference. The functional and behavioral requirements for a visual flight research facility (VFRF) emphasize visual and motion simulation but include performance assessment, laboratory calibration, and control and test station requirements. Information collected from special helicopter flights at NOE altitudes, pilot interviews, analysis of relevant data, and review of other pertinent research facilities was used in engineering analyses and trade-off studies to determine specific performance values and alternative facility concepts.

Findings:

Eight alternative facility configurations and capabilities were considered, including simulation of a day-and-night (color) capability or a monochrome night capability. A night visual display system with sensor aiding was selected because it represented the most cost-effective approach to an acceptable range of high-priority, night NOE studies in the earliest time frame. The pilot's night vision capability along with ways to improve his performance and increase his survivability, represents a most critical NOE problem. Low-cost sensor aids and techniques would permit wide utilization by present and planned helicopters. In addition, because perceptual and behavioral research is emphasized, complete simulations of helicopter aerodynamics, instrumentation, and motion characteristics would not be needed in the facility.

Utilization of Findings:

The proposed facility would provide a relatively low-cost, versatile test bed that should contribute directly to the safety, survivability, and mission effectiveness of helicopters at NOE altitudes. The visual concepts and principles could serve as focal points for future helicopter displays and cockpits. The planned flexibility and growth capability of the device would permit research utility for many years at the cost of a fraction of the potential savings.

This report can also guide others in developing the behavioral and functional requirements for comparable research and simulation facilities.

BEHAVIORAL AND FUNCTIONAL REQUIREMENTS FOR A VISUAL FLIGHT RESEARCH FACILITY

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PROBLEM

Sophisticated surface-to-air weapon systems have forced helicopters to fly at nap-of-the-earth (NOE) altitudes or to use terrain masking for survivability. This mode of flight is highly dependent on visual flight reference and involves visual problems not normally encountered at higher altitudes. The visual characteristics imposed by flight in close proximity to terrain features can be described as follows:

- Relatively short viewing ranges,
- Large visual field of view,
- Prominence of and dependence upon the viewed scene for maneuverability,
- Higher angular velocities of the viewed scene,
- Frequent noncorrespondence between the visual line-of-sight and the flight vector,
- Significantly reduced visual frame of reference with lower illumination levels,
- Visual discrimination of trees and foliage, and
- Judgment of depth and distance.

The above factors greatly increase the pilot's and copilot's task loading and subject them to the following visual demands and behavioral problems.

- Loss of visual resolution;
- Need to avoid obstacles;
- Limited reaction time;
- Loss of geographical orientation;
- High workload;
- Intense visual concentration;
- Problems due to sun or moon glare, rain, and haze;
- Stress;
- Vertigo; and
- Physical endurance.

In light of the above statements, the following observations can be made.

1. The safety and survivability of helicopter flight at NOE altitudes will depend directly upon the adequacy with which the pilot perceives and responds to his visual cues, both in the natural world and on his display.

2. Mission effectiveness will depend upon the degree to which the pilot's and copilot's visual capabilities are augmented.

3. Visual aids will become the primary focal points about which future helicopter cockpits are developed.

Little relevant data exist on pilot capabilities in, and display requirements for, the NOE environment, because most visual research has been conducted for high-altitude aircraft. The higher speeds, longer slant ranges, and different pilot tasks of high-altitude aircraft present visual problems and requirements different from those of NOE flight. Also, few research facilities now emphasize behavioral considerations. Most of the existing research facilities have been limited to engineering problems such as sensor development and missile guidance. Little or no capability exists to study visual phenomena (Hurd, 1973), particularly within the low-altitude flight regimes flown by helicopters.

The hazards associated with NOE flight, particularly at night, will not permit research studies under all desirable scenarios and illumination levels. Similarly, it will not be possible to measure, control, and repeat environmental conditions to the level necessary for effective visual studies. As a result, a highly specialized visual flight research facility (VFRF) is needed to help determine the unique visual and display requirements associated with NOE flight.

OBJECTIVES

The objectives of this report are to describe the behavioral and functional requirements for a VFRF. This information has served as the basis for engineering and trade-off studies to establish the necessary performance requirements, system concept, and specifications for procurement purposes, as reported in King, 1975.

A primary aim in establishing these requirements was to specify a research facility which met comprehensive behavioral requirements from stimulus inputs to performance measures. Many research facilities used to address operator problem areas are either modified engineering facilities or were designed solely by engineers without full appreciation of behavioral requirements. Any research facility which purports to assess human capabilities must be designed from the behavioral viewpoint if its objectives are to be met. The proper perspective will result in a simpler, less costly, and more effective system.

Research Goals

The basic research goals of the VFRF are to enable studies leading to new information and advances in the state of the art. A capability is desired for both basic and applied efforts. Specific goals in this respect are as follows.

1. To assess basic pilot visual capabilities in the NOE environment,

2. To investigate new visual aids and display concepts for the improvement of pilot performance,

3. To establish visual requirements and display design criteria to guide engineering development,

4. To evaluate alternative sensor systems, techniques, and procedures to determine cost-effective solutions,

5. To conduct comparative hardware and concept studies to determine optimum design parameters, and

6. To provide latitude for assessing allied visual problem areas within the Army, such as surveillance, target acquisition, and remotely piloted vehicles (RPV).

Design Goals

To meet the above objectives, a facility with the following special characteristics is required.

- Control and repeatability of system parameters (e.g., illumination levels, display gray scale control, etc.), to permit the precise replication of desired performance levels for the comparability of data,

- Multiple levels of parameter control to permit a wide range of discrete and controlled stimulus conditions to determine performance thresholds,

- Comprehensive interrelationship of parameters to enable the study of a wide range of stimulus interactions as they affect pilot performance,

- Scope and latitude of potential studies to permit a wide range of planned studies, including unanticipated requirements in the visual area,

- Flexibility of utilization to permit the rapid accommodation of different research needs, and

- Comprehensive performance measures and data recording technology to assure the valid and discriminative assessment of pilot performance.

Psychophysical Validity

A critical requirement of the VFRF will be the use of a windscreen display of the "external" world that will permit valid psychophysical experiments; that is, tests that can be expected to produce results approximating the visual performance levels achieved in the real world. This will involve the appropriate simulation of the critical visual parameters, such as display illumination that will permit normal levels of visual resolution. Associated with this requirement are those minimum motion requirements that will assure the validity of the operator's psychomotor actions in response to the visual display. Realistic task loading and helicopter environmental cues are similarly important for a valid research context.

Relation to Field Tests

The facility should be developed with full knowledge of the supplementary field test research capability available by means of operational helicopters at Fort Rucker, Ala., and elsewhere. In this regard, the need for complete operational realism can be relaxed in such areas as instrumentation, aerodynamics, and cockpit motion. The research facility and field tests can be used to supplement each other. Concepts identified in the laboratory can be tested under realistic helicopter and operational conditions in the field. At present, important performance parameters which are not known or pretested before the undertaking of operational field tests may nullify the effectiveness of a field test. Similarly, problems identified in the field can be studied under controlled laboratory conditions.

Constraints

Certain constraints were established in order to assure the development of a reasonable VFRF concept.

- Relatively low cost and early development within the state of the art,
- Research limited to visual and crew performance,
- Relaxation of the need for complete operational realism compatible with research requirements, and
- Design conceived for gradual development and growth in two or more compatible phases.

A critical consideration was to develop a "stay-young" facility with maximum flexibility and growth potential for a wide range of visual problems.

RESEARCH SCOPE

The research problem areas to be addressed in the VFRF, which are delineated in the Technical Supplement, are as follows.

1. Visual capabilities,
2. Visual aids/sensors,
3. Display parameters,
4. Pilot proficiency,
5. Crew coordination,
6. Navigation, and
7. Cockpit layout (auxiliary aids and displays).

These areas are consistent with the research program recommended by the conference on "Aircrew Performance in Army Aviation" that was held at Fort Rucker and sponsored by the office of the Chief of Research, Development, and Acquisition (U.S. Army, 1974).

Mission success is a function of many interacting system and pilot performance variables. The research program is designed to assess, understand, and improve the relationship and contribution of these variables, both singly and in combination, to derive the most cost-effective solutions relative to performance criteria as stated by the user. This approach is illustrated in Figure 1.

The figure shows the research problem areas in the center. Performance in these areas is influenced by mission, environmental, personnel, and man/machine combinations, or the total operating system context. In addition, these variables interact with one another and collectively focus and result in system performance. A sample of the performance variables that can be measured and integrated is shown in Table 1. These variables will be processed to yield composite and weighted performance measures.

APPROACH

The research facility should be developed in two or more phases. The first phase would be limited to the highest priority problems, would allow quicker development, and would provide an experience base and subsequent refinement before additional growth. Later phases would expand device capabilities. However, this study explores a total concept, to assure that successive concepts would be compatible with one another and to understand the interactions and cost implications involved. Considered at the outset, a wider range of capabilities may not appreciably add to the development costs and will assure their compatibility if added later.

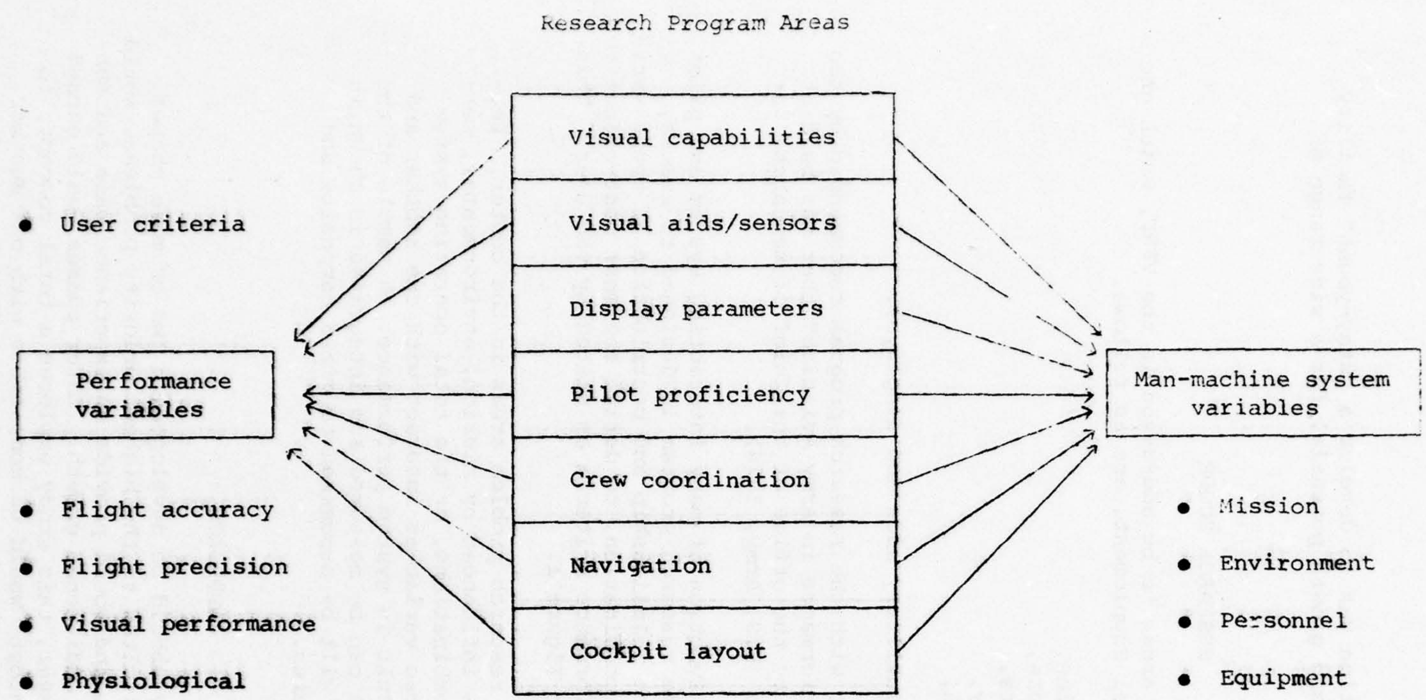


Figure 1. Research system.

Table 1

Sample of Performance Measures

<u>Integration measures</u>

- Flight accuracy
  - position
  - heading
  - airspeed
- Flight precision
  - number of control displacements
  - number of control reversals
  - flight variability about thresholds
- Stress
  - heart rate
  - blood pressure
  - breathing rate

<u>Collateral measures</u>

- Visual performance
  - eye movements
  - fixation time
  - detection/recognition
- Communications
  - type
  - frequency
  - content
- Residual work capacity

The basic functional requirements of the VFRF are these:

1. Direct visual flight reference (VFR) by means of a "real-world" display;

2. Aided visual capabilities by means of forward looking infrared (FLIR), television (TV), and low light level TV (LLLTV) type systems;

3. Simulation of day and night conditions, including the effects of atmospheric attenuation, and possibly sun position;

4. Capability of pilot transition from the "real world" to a cathode ray tube (CRT) display; and

5. Controlled and repeatable parameters compatible with field test validation.

These basic requirements, the proposed research effort and the objectives established for the VFRF, guided the analytical effort, which consisted of two parts. The first part, described in this report, established the specific functional and behavioral requirements for the VFRF. The second part, reported in King (1975), established the specific performance, system concept, and system specifications to meet the functional and behavioral requirements. Initial study requirements for these efforts are given in Appendix A.

The analyses conducted for the present document were aided immeasurably by the field test program being conducted by the Army Research Institute (ARI) at Fort Rucker, Ala. As part of these analyses, NOE flights were taken for familiarization purposes. Special flight scenarios and maneuvers were also flown with photographic documentation. Instructor pilots were interviewed and asked to observe special conditions. Researchers also visited the Combat Developments Experimental Command (CDEC) at Fort Ord, Calif. Data from questionnaires given to helicopter pilots engaged in special night NOE operations (U.S. Army, 1973) were analyzed. From these visits, behavioral and functional requirements were derived, and an intensive review of visual and applicable psychophysical performance data and a selected review of other research facilities were made. The resulting data and analyses are reported here.

SELECTED VFRF CONCEPT

A night visual display system with sensor aiding was selected as the initial concept, with a windscreen display for a single operator and a secondary crew compartment with CRT monitors of the windscreen display to permit coordinated crew member activities. This initial concept was selected due to priority, cost, and state-of-the-art considerations. As described in the Technical Supplement, this concept represents the most cost-effective approach to accomplish an acceptable

range of night NOE studies in the earliest time frame. The pilot's night vision capability, along with ways to improve performance and increase survivability, represents the most critical NOE problem today and for the foreseeable future. Low-cost sensor aids and techniques are particularly needed to permit wide utilization by the large inventory of present and planned helicopters. The system design provides the capability to evaluate the operators' basic visual performance at night and permits research on the effectiveness of various low-light-level aids. The proposed system is illustrated in Figures 2a and 2b. A description of key systems characteristics which enable this approach to satisfy the basic VFRF functional and performance requirements is given below. A list of specific system performance characteristics is contained at the end of the section on concept selection.

Windscreen Display

The windscreen visual display system includes the following principal subsystems:

- Three-dimensional terrain model,
- Model illumination,
- Wide field of view (FOV) optical probe,
- Monochrome TV camera pickup,
- Gantry/servo-controlled, optical probe transport,
- Electronic processor (including special effects generation),
- Collimated-image-type windscreen display, and
- Electro-optical (E-O) sensor system.

With overall test station integration and control, this sytem is designed to cause the windscreen display to properly respond to the pilot subject's flight control commands in all 6 degrees of freedom (DOF). Effectively, the operator is provided with nonprogramed, simulated helicopter flight capability in three-dimensional space.

When the simulated sensor system control is in an "uncaged" mode, the test subject is free to remotely control it by using a manual track stick or a servoed helmet sight, or by pointing the simulated sensor axis in pitch and yaw, independent (within specified design limits) of the simulated attitude of the helicopter airframe, as denoted by the scene orientation presented on the windscreen display. In this mode, the special sensor unit (probe) is "decoupled" from the airframe simulated roll motions, thus providing the effect on the special display(s) of roll-stabilized sensor operation. The operator also selects the sensor FOV size as a function of the particular task being performed (e.g., terrain avoidance, target area search).

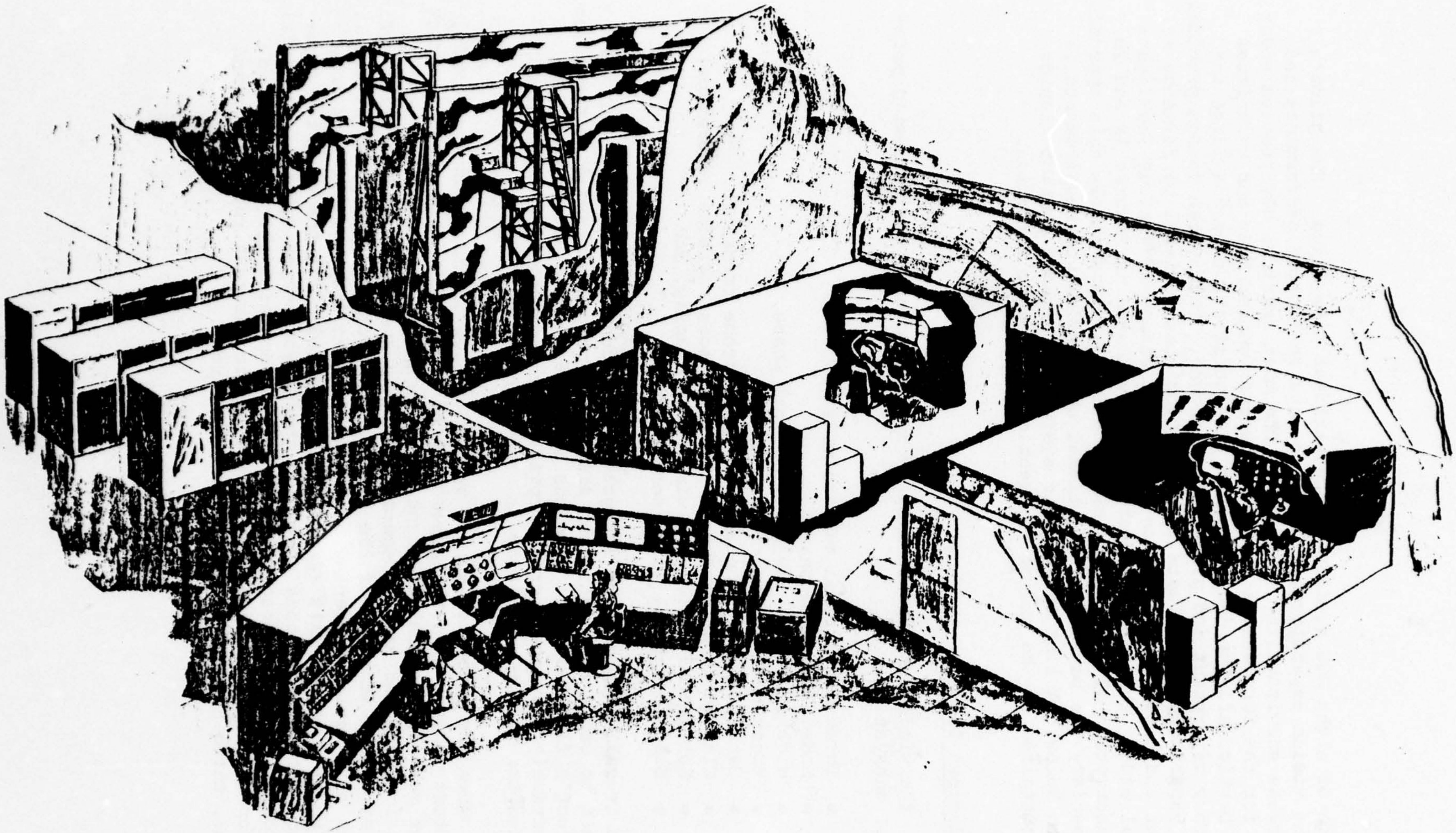
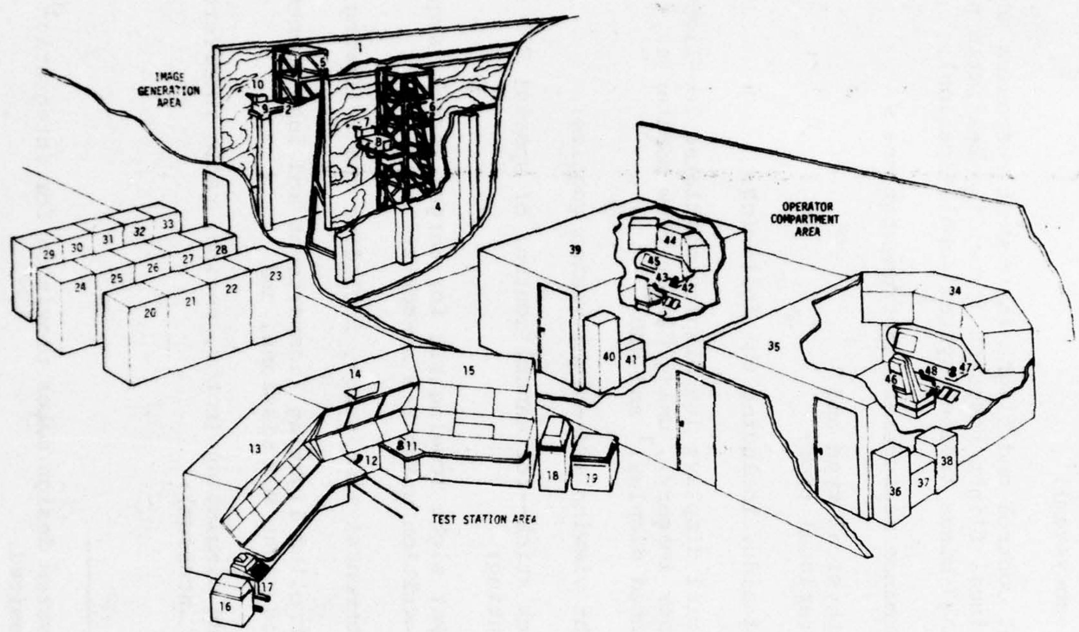


Figure 2a. Visual flight research facility--concept.



ELEMENT NO.	IDENTIFICATION
1	TERRAIN MODEL - E-O SENSOR
2	MODEL ILLUMINATION - E-O SENSOR
3	TERRAIN MODEL - WINDSCREEN
4	MODEL ILLUMINATION - WINDSCREEN
5	GANTRY/TRANSPORTS - E-O SENSOR
6	GANTRY/TRANSPORTS - WINDSCREEN
7	TV CAMERAS - WINDSCREEN
8	OPTICAL PROBE - WINDSCREEN
9	TV CAMERA - E-O SENSOR
10	OPTICAL PROBE - E-O SENSOR
11	TRACK STICK
12	FLIGHT CONTROLS (SIMPLIFIED)
13	SYSTEM CONTROL STATION
14	FLIGHT MONITORING STATION
15	MEASUREMENT CONTROL STATION
16	CHART RECORDER
17	TELETYPEWRITER
18	CHART RECORDER
19	POSITION PLOTTER
20	COMPUTER CONTROL
21	PUNCHED TAPE READER
22	TAPE PUNCH
23	LINE PRINTER AND CONTROLLER
24	AUDIO ELECTRONICS
25	DIGITAL COMPUTER - CPU #1
26	DIGITAL COMPUTER - CPU #2
27	DISK OPERATING SYSTEM - CPU #1
28	DISK OPERATING SYSTEM - CPU #2
29	POWER CONTROL
30	INTERFACE D/A
31	INTERFACE A/D
32	AUXILIARY ELECTRONICS
33	AUDIO RECORDER
34	COLLIMATED WINDSCREEN VISUAL DISPLAY HOUSING
35	PRIMARY OPERATOR COMPARTMENT
36	INTERFACE CABINET
37	AIR CONDITIONER
38	G-SEAT CONTROLS/ACTUATORS
39	SECONDARY OPERATOR COMPARTMENT
40	INTERFACE CABINET
41	AIR CONDITIONER
42	TRACK STICK
43	FLIGHT CONTROLS (SIMPLIFIED)
44	DIRECT VIEW WINDSCREEN DISPLAY MATRIX
45	SPECIAL E-O SENSOR DISPLAY
46	G-SEAT AND VIBRATOR
47	TRACK STICK
48	FLIGHT CONTROLS

Figure 2b. VFRF concept description.

Primary Operator Compartment

This complex is equipped as follows.

- Single crewmember simulated flight compartment (including flight controls and instruments);

- Wide FOV "infinity focus" type monochrome windscreen display--provides 6 DOF scene dynamics via windscreen image generation system;

- Motion simulation (G-seat)--to provide key acceleration "on-set" cues coordinated with visual display--(plus seat vibration subsystem);

- Flight control and flight instrument responses adequate for NOE visual flight research (providing realistic pilot "task loading" minus trainer system sophistication);

- Performance measurement instrumentation:

  - Biophysical type and
  - Operational type;

- Visual aids, including the following:

  - Special displays (to display simulated low-light-level E-O sensor imagery), using direct view monitor(s),[1] helmet-mounted display,[1] and HUD;

  - Night viewing aid--night vision goggles;

  - Track stick--for manual control of special E-O sensor pointing;

  - Helmet sight (cueing aid for target search, acquisition, and recognition using E-O sensor system);

- Environmental simulation, including the following:

  - Controlled lighting (compartment and instruments) for simulated night NOE missions, and

  - Noise simulation (rotor, engine, radio interference, via the intercom);

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[1] Basic VFRF system design makes provision for integration of these units, when desired.

- Flight intercom--tied to test station complex, including secondary operator compartment.

Secondary Operator Compartment

- Manned by second member of flight crew (pilot or copilot);
- Simplified flight control plus necessary complement of flight instruments;
- Direct-view type windscreen TV display array;
- Special E-O sensor track stick and display(s);
- Controlled lighting of compartment interior and instruments for simulated night viewing conditions;
- Flight intercom--tied to test station complex, and including flight compartment; and
- Noise simulation (rotor, engine via the intercom).

Test Station Complex

The plan of this complex is as follows.

1. System control station
    - Manned by system control operator (SCO);
    - Contains the controls and displays required to operate and calibrate all visual stimulus mechanisms in the VFRF, via the computer--including CRT keyboard interface;
    - Contains system calibration, monitoring, and checkout requirements; and
    - Contains all mechanical and electrical operational safety interlock controls.
2. Measurement control station
    - Manned by measurement control operator (MCO)--also termed "Experimenter."
    - Contains all necessary controls to establish experimental scenarios and initial parameter values.

- Contains control and display devices required to select desired measurements, to operate test measurement and recording equipment, and to present selected data to the MCO for real-time monitoring and for postexercise debriefing purposes. These functions are accomplished via the CRT-keyboard computer interface.

- MCO also may assume second (remote) crewmember's function by performing simplified navigation or piloting functions from the flight monitoring station console area.

3. Flight monitoring station

   - Contains direct-view type windscreen display array, special E-O sensor track stick and display, and simplified flight control and key flight instruments.

   - SCO uses display outputs in setting up initial test conditions and in periodic monitoring during test runs.

   - When manned, the MCO shifts to this location, time-sharing it with his measurement control functions.

4. Computer complex

   - Has general-purpose, commercially available computer of solid-state, integrated circuit construction:

     - Memory size--at least 32,768 words,
     - Word length--minimum word length, 16 bits

   - Acts as interface for the total VFRF;

   - Contains peripheral equipment;

   - Contains all software required for VFRF to operate as a complete integrated system; and

   - In addition, the computer system will provide simultaneous computation for, and control of, all applicable test station functions and other equipment as required in the VFRF.

The above concept will provide a relatively low-cost,[2] versatile facility to evaluate the visual capabilities and requirements of helicopter pilots at NOE altitudes. The planned flexibility and growth capability of the device will permit research utility over several years. Its cost will be a small fraction of the present helicopter inventory

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[2] Estimated 1975 cost was $2.8 million.

and that of potential savings in aircraft development and lives saved. Remaining growth options will include

- Day/color presentation,
- Collimated windscreen display for second crewmember,
- 6-degree large hydraulic motion base,
- Solar and lunar simulation, and
- Alternate cockpit configurations.

The proposed facility will differ from a training device in several significant ways. The device will be simpler in its cockpit configuration, instrumentation and simulation fidelity, aerodynamics, and motion base. It will be more sophisticated than a trainer in these respects:

- Higher fidelity visual display to permit psychophysical studies,
- Ability to calibrate and repeat conditions,
- Comprehensive and sophisticated performance measures, and
- Flexibility of utilization and generalizability (no fixed helicopter configuration).

The facility will also cost less initially and will cost less to operate than most trainers or other more complex research facilities.

CHARACTERISTICS OF NAP-OF-THE-EARTH FLIGHT

NOE flight characteristics are described below as a general background for the requirements presented in this report. This information will also help to determine such considerations as optical probe clearance, terrain model size, motion requirements, and flight dynamics. The implications of this information are presented in later sections as applicable.

Definition

"NOE is flight as close to the earth's surface as vegetation and obstacles will permit, which generally follows the contours of the earth" (Thompson, 1973). Terrain flight is the current officially recognized term for this mode of flight, which recognizes that any altitude can be flown if terrain masking is available (e.g., mountains and hillsides). NOE flight is usually initiated in the forward edge of a battle area (FEBA).

In NOE flight, both altitude and airspeed are varied in order to take advantage of topographical features, speed being an important variable to compensate for terrain difficulty. In contour flight, airspeed is constant, while altitude varies. Altitude is usually varied to maintain 50 ft over all terrain features at about 100 knots constant airspeed. In low-level flight, both airspeed and altitude are constant. In this mode, flight about 100 ft above ground level (AGL) is maintained over the highest terrain feature at about 100 knots constant airspeed. The difference between these modes of flight is illustrated in Figure 3.

Flight Characteristics

Tree Clearance. In rolling and heavily treed terrain, such as that found at Fort Rucker, the helicopter will be flown as close to the trees as the separation between the trees and the physical dimensions of the helicopter will allow. The UH-1H cabin is 13 ft wide, and the rotors are 48 ft wide. The following "typical" flight maneuvers will occur relative to the tree separations shown. Results can be expected to differ with less experienced pilots. Average clearance of the cabin or the rotors is 2-1/2 ft on each side. In the latter two cases, the treetops are above the eye level of the pilot. In a field, the pilot flies appreciably below the treetops at the edge of the field--as close to the surface of the earth as vegetation allows. Hence, it is not unusual for the cab of the helicopter (or the pilot's line of sight) to be below treetop level with the rotors skimming tops of adjacent trees. In valleys, draws, and similar depressions, the

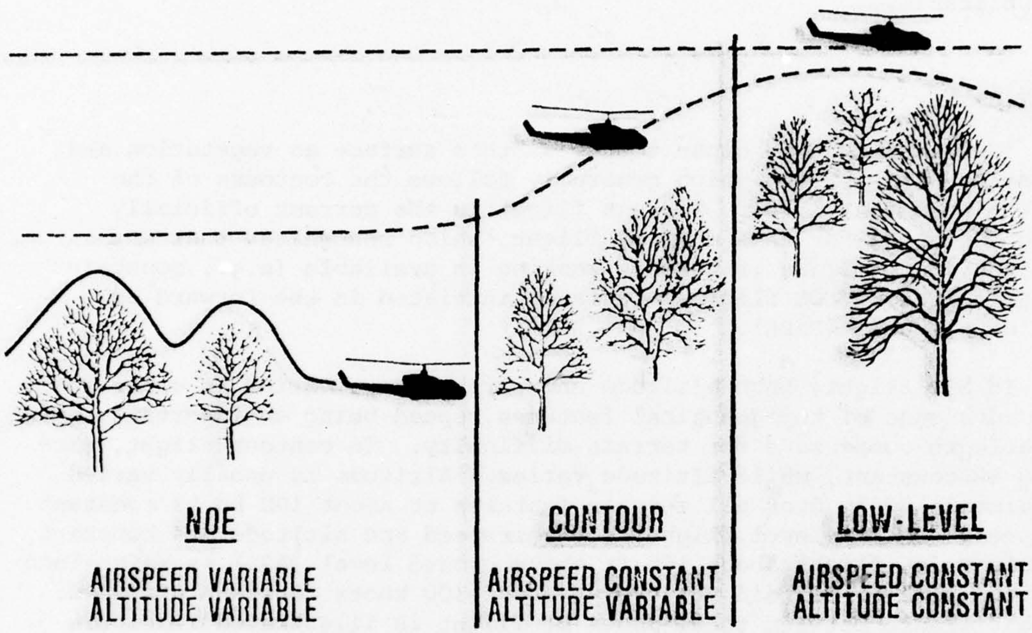

Figure 3. Illustration of NOE, contour, and low-level flight (from U.S. Army, TC1-15, 1973).

helicopter is also below the level of the surrounding terrain. This type of flight profile leaves the pilot with little margin for error or reaction time if distances are misjudged.

Tree separation (in feet)	Helicopter altitude
2-15	Skids of cab are at treetops
18	Cab beneath trees and rotors skimming treetops, with approximately 2-1/2 ft clearance between trees and cab
20-40	Rotors banking to fit between and below treetops; clearance varying with rate of bank
53	Rotors just below (by about 1 ft) treetops

Viewing Distance. A pilot's minimum viewing distance is about 500 ft ahead (subject to speed), since no corrective actions are possible within such distances. His average maximum reported viewing range is between 1,500 and 4,500 ft. Analyses of motion picture films, however, indicate that a pilot's average viewing range is between 500 and 1,000 ft, as ascertained by the time at which prominent objects first appear and pass under the fuselage of the aircraft. Hence, he is looking at immediate obstacles just beyond his reaction time capabilities and is looking farther ahead to plan for and avoid other objects. At night, the viewing range becomes even shorter, relative to the illumination level and speed flown. Due to the required visual concentration, the pilot's head motions are relatively limited, and his eyes dart about as he fixates on one object and another. Peripheral vision, however, is considered important to maintain general attitude orientation. The pilot's primary field of view is 120°, with peripheral viewing of 30° at each side. The navigator, on the other hand, views the scene approximately 3,000 ft ahead and, unlike the pilot, moves his head and viewing gaze freely about. The effects of haze (due to increased air density at sea level) are pronounced as one looks to the horizon, significantly reducing the clarity of objects in the immediate distance. The resolution of objects is also poor due to the density of foliage and the speed at which the craft flies by.

Air Speed. At NOE, airspeed will generally be a function of the crew's ability to navigate or the maximum safe speed that the terrain will allow. Airspeed can vary from zero knots to Vne (velocity not to exceed, or red-line). Average airspeed falls between 30 and 40 knots. There is also an important relationship between airspeed and wire (or obstacle) detection and avoidance. Total system response time has

been estimated at approximately 5 seconds (Thompson, 1973). The effects of this response time are shown in Figure 4.

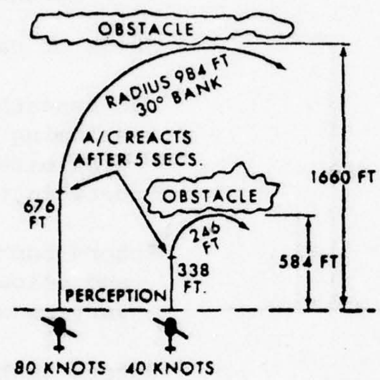

Figure 4. Aircraft reaction time (from Thompson, 1973).

At 80 knots, an aircraft requires 1,660 ft to turn 90°, and at 40 knots, 676 ft. With limited visibility, sufficient time would not be available for an aircraft flying 40 knots to avoid an obstacle seen at approximately 500 ft (unless NOE deceleration or a quick-stop maneuver was employed).

Flight Time. Flight time during NOE is determined by several considerations, primarily fuel capacity. The UH-1, for example, has approximately a 2-hr fuel limit; 1-1/2 h is more typical if above-average load conditions exist. The time distributions for the field experiments conducted by ARI (Fineberg, Meister, & Farrell, 1978) are approximately as follows (average speed, 30 to 40 knots over a course 26 to 32 km long):

30-45 min	warmup and transit
10 min	approach to IP for hover check
20-40 min	NOE flight
30-45 min	return to base.

Actual NOE flight time is a function of how well the copilot navigates or how well the pilot can maneuver (one or the other being the limiting case). Flight time is also limited by pilot endurance. Due to the stress and unusual concentration required by NOE flight, pilot endurance is approximately 2 hr. Under night conditions, pilot endurance reduces to about 1-1/2 hr.

Aircraft Motion. During NOE flight with a qualified pilot, motion forces are barely perceptible to a passenger. The pilot plans ahead and glides his aircraft between obstacles in a smooth, continuous manner. Abrupt or large excursions would be dangerous at the terrain clearances flown. The uncertain pilot is more hesitant and abrupt in his control motions, but usually flies at a higher altitude. In general, the aircraft motions are of a low-amplitude, high-frequency type. This, in part, is due to the sequence of control actions used to control aircraft altitude at NOE (e.g., the use of the collective to initiate the maneuver, followed by the cyclic and compensated for by the antitorque pedals). As described elsewhere in this report, acceleration rates are estimated to be of the following magnitudes: roll, $25^{o}/sec^2$; pitch, $18^{o}/sec^2$; and yaw, $130^{o}/sec^2$. The motion cues between lower and higher speeds (e.g., 40 knots and 100 knots) may be essentially the same due to the higher altitudes flown with increasing speed. This reduces the need for abrupt motions in order to avoid obstacles.

Navigation. An ARI project determined the capability of helicopter pilots to navigate at NOE altitudes (Fineberg et al., 1978). It was found that average pilots without special navigation training at NOE altitudes would find the initial point (IP) 67% of the time, and subsequent landing zones 63% of the time. Their ability to maintain a course within 250 m and 1,000 m of a nominal course line was 90% and 91%, respectively.

Flight at Night

The characteristics of NOE flight at night were determined by extensive field tests conducted by the Combat Developments Experimental Command (CDEC) at Fort Ord and at Hunter Liggett, Calif. The goal of the CDEC program, "Attack Helicopter--Clear Night Defense," was to determine pilot performance capabilities with unaided vision during night NOE flight against which aided techniques could be evaluated (U.S. Army, 1973). In contrast to the relatively flat and heavily treed terrain of Fort Rucker, the terrain at Hunter Liggett is rugged and hilly, with highly varied tree density, including appreciable sparseness. The pilots required approximately 30 hr of ground training and 87 hr of flight training at night before NOE altitudes could be reached. For example, 2 weeks were spent between 1,000 and 500 ft, 3 weeks between 500 and 250 ft, 3 weeks around 250 ft, and the balance of the time at NOE, which was about 50 to 125 ft. The results of their program indicated that pilots "...can maneuver at altitudes within 250 feet of the ground under a clear night, no moonlight condition, but cannot acquire and attack tank targets" (U.S. Army, 1975).

Pilots associated with this program were interviewed about the visual and flight characteristics of NOE flight at night. The following information was reported. During NOE and under the lowest illumination level (no moon), the helicopters were reported as being

125 ft above the trees, and, under full moon conditions, only 50 ft above. (One pilot, however, stated that the aircraft was "in and among the trees," similar to our daylight experience at Fort Rucker.) At the lowest illumination levels, the aircraft flew between 0 and 20 knots. In general, the aircraft flew lower and slower as visibility decreased. Under no moon conditions, visibility ranged between 150 and 300 ft. Telephone and power wires, however, could not be seen under any circumstances.

The lack of depth perception was reported to be the primary visual problem and the loss of size constancy. The pilots could not tell whether a tree was far off or close by, relative to its size alone. The lack of depth perception was sufficiently serious that, if pilots knew they had to return to a lower altitude, they would not fly high to avoid the problem of transitioning to the lower altitude. The pilot's primary cue to depth (and airspeed) was looking straight down from the side window and then trying to interrelate what he saw with his estimated slant range and radar altimeter reading (AGL).

Without a visible horizon, the pilots would lose orientation but could not transition to instruments effectively because of danger of not seeing obstacles. Thus the pilots were looking out of the windscreen more than 75% of the time. They placed heavy reliance on peripheral vision. Shadows cast by hills and trees posed serious problems, leading to further loss of visual resolution as well as peripheral vision when in valleys. On the other hand, loss of orientation due to moon blindness was not uncommon. In this respect, the dark-adapted eye was very sensitive to light changes. It was felt, though not effectively verbalized, that new and significantly different visual cues are learned and integrated at night. Night vision goggles introduced still different visual problems and required the learning of different visual cues. As noted earlier, pilot endurance was limited to approximately 1-1/2 hr of flight time, due to the unusual stress and concentration involved.

DEVELOPMENTAL CONSIDERATIONS

Five basic areas collectively determine the characteristics of a research facility.

- Proposed range of research studies;
- Stimuli or image generation material, e.g., terrain model;
- Visual display, e.g., virtual image;
- Laboratory equipment and controls, e.g., illumination; and
- Type of subject.

All these areas are closely interrelated and must be treated together as a system. Many difficulties have arisen in the past when one area

or another (usually the display system) has been stressed without careful consideration of the other factors. In addition, many alternatives exist in each area which require careful consideration or "tradeoffs" in terms of effectiveness and cost.

Range of Research Studies

The following research problem areas, selected for investigation by the VFRF, represent a fairly broad range of test objectives. These research goals served as the primary reference for the evaluation of alternative approaches and concepts. The degree to which all of the requirements can be satisfied is a function of cost and state-of-the-art considerations. The selected concept, its rationale, and the test goals that can be met are described in a subsequent section.

Visual Capabilities. Determination of the pilot's dynamic visual capabilities under varying altitude and illumination levels with regard to discrimination of terrain features and target acquisition. Analysis of visual scanning procedures, workload and fatigue, and maintenance of visual orientation in space. This information will indicate what a pilot can be expected to accomplish visually, relative to mission objectives, under varying NOE flight conditions.

Visual Aids/Sensors. Investigation of special sensors, aids, and display formats to aid and augment pilot performance and visual capabilities during flight under day, night, and poor atmospheric conditions. Head-up displays, stereoscopic and night visual aids, multiple sensors, and the integration of information on displays are of interest. This information will help to determine the most cost-effective way of improving pilot visual capabilities under different environmental constraints relative to mission requirements.

Display Parameters. Determination of optimum display parameters for pilot viewing, including such considerations as FOV, display size, and information content. Any system that is dependent upon the eye must be designed in keeping with visual requirements (or "from the eyeball out") to be effective. This information will establish parameters to help guide engineering development.

Pilot Proficiency. Investigation of basic pilot performance capabilities and limitations in the NOE operating environment and as a function of man/machine combinations and interactions, including attention to stress causative factors, pilot endurance, and performance decrement. This information will determine basic pilot proficiency under various flight scenarios and environmental conditions, including performance criteria and measures of effectiveness for the evaluation of alternative techniques and field applications.

Crew Coordination. Determination of the optimum distribution of work, workload, communication, and procedures between the pilot and copilot under varying mission and environmental factors. This information will help to distribute workload and facilitate coordination for the accommodation of increased mission demands, without the increase of crew size or the relaxation of other requirements.

Navigation. Investigation of aids, techniques, and procedures to improve navigation, with special emphasis on the coordination and simplification of tasks under difficult flight conditions. This information will help to increase the probability of a crew finding their designated target area in a minimum of flight time.

Cockpit Layout. Investigation of cockpit parameters which limit or aid the performance of NOE flight, including such considerations as the reduction of sun glare, placement of displays and the sharing of instruments between crew members. This information will help to facilitate pilot performance under otherwise trying flight conditions.

Image Generation

An image generation source or stimulus materials are necessary to provide the visual inputs for a visual display. A terrain model is commonly accepted as the primary stimulus source material. Several alternatives exist, however, and some are equally effective from an image point of view, and are considerably less expensive. Primary among these are films, transparencies, videotapes, and photographs. Often higher resolution and detail can be achieved with these latter systems. (Existing drawbacks will be described later.)

Computer-generated imagery (CGI) is another rapidly developing alternative. CGI represents the latest state of the art. The images are created by a series of flat facets bounded by straight lines or small dots, depending upon the technique used. Anything that can be described can be generated. Focus and perspective problems do not exist. The pilot's perceived scene can be moved throughout the environment and pass through the simulated scene. Unique display techniques, which cannot be achieved by other means, are possible. For example, two aircraft can be flown, with each "pilot" having an outside view of the other in flight. "Dogfights" and other intricate tactics can be achieved. This technique also lends itself to digital land mass simulation, which is used to convert maps and other two-dimensional imagery into radar or FLIR displays in both plan and perspective views. Highly realistic displays are achieved with a capability to readily change the scale factor of the displayed scene and to correlate the scenes with the actual operational scopes.

Nevertheless, the above techniques also present certain disadvantages. Films, for example, appear to have the following limitations.

1. The ability to photograph distortionless imagery at NOE altitudes;

2. Effective contrast control;

3. The ability to conduct closed-loop studies, i.e., interactive with pilot control;

4. The ease with which sensors can be used;

5. The ability to maintain the comparability of stimulus materials (and contrast control) for aided and direct viewing studies; and

6. The loss of depth information, as well as perspective problems due to the two-dimensional medium.

Some film costs may also be appreciably higher than other approaches. This appears to be the case for the Variable Area Motion Picture (VAMP) system. This is a 70mm movie system which projects a variable 35mm scene. It provides maximum visual fidelity and partial closed-loop dynamics. An unexpected limitation of this system appears to be the initial and recurring costs of the required film. First-copy films cost more than $200,000, with at least $40,000 for new copies. Each film has a 1-year lifespan. On a life-cycle basis, Singer engineers estimate that the VAMP system costs more than a terrain model system.[3]

The imagery of computer-generated displays is cartoonlike in characters, due to the need for a large computer capacity to draw fine detail. The drawing of realistic trees and landscapes details would be particularly difficult. Detail is important for NOE studies to permit adequate assessment of the pilot's perceptual response, including depth perception, in the NOE environment. The resolution and detail needed for NOE, as a result, would be extremely complex and costly. Very effective night scenes, however, have been simulated by means of dots and simulated point light sources for aircraft landings.

The terrain model approach, on the other hand, imposes unique considerations. The primary disadvantage is the trade-offs required between scale factor, size of the area to be simulated, level of detail, and resolution as it is affected by the characteristics of the optical probe. Effective resolution, when the probe is at treetop level (particularly in the vertical plane) provides a difficult optical challenge. This aspect is treated fully in a companion document to this report

[3] Personal communication with Mr. J. Bradish, Singer Simulation Products Division, 18 December 1974.

(King, 1975). A terrain table was nevertheless selected, because it appears to offer the greatest flexibility and control of experimental conditions and is compatible with most of the requirements of the "VFRF." In particular, it provides the true visual analog of the real world, including the important cues for depth perception (as discussed later). Subtle parameters such as realistic perspective and shading are also readily produced, as is color.

Films and CGI techniques can be used as supplementary stimulus inputs. For example, films taken in the field or from other three-dimensional sources such as terrain models will be suitable for study areas such as navigation and fire control. They can provide flexibility and can be important supplements to a terrain model (e.g., extending flight time at higher altitudes). With an appropriate visual display (e.g., a virtual image), CGI can be used to supplement the terrain table with new target scenes. The digital land mass technique described above, although expensive, could also provide an ancillary capability, to a camera-model approach, for the simulation of FLIR and radar.

Visual Display

Since the VFRF is primarily a visual research facility, the visual display employed assumes special significance. Factors that will influence selection of a display system for visual flight reference include resolution, highlight brightness, distribution of the light evenly over the surface, general illusion of depth (avoidance of flat scenes), and scene perspective, including simultaneous perspective viewing by two men (if used) and the avoidance of motion parallax during pilot head motions.

Several display methods can be considered for visual research studies. The simplest would be direct viewing of a terrain model. This has been accomplished by placing subjects in a cab in such simulators as those at the Martin Marietta Guidance Development Center. However, because of scaling considerations, this is only effective for studies at simulated high altitudes. The primary alternatives for NOE studies appear to be real-image TV projection and virtual image displays.

Real-image projection consists of an image projected onto a screen by one or more TV projectors. At present, this approach has been the one most commonly used, since it is relatively simple and affords large fields of view. But it is characterized by low screen brightness (e.g., approximately 2 FL). If the screen is placed at a sufficient viewing distance from the subject, a resolution capability can theoretically be achieved that approaches the resolution limits of the human eye (i.e., 1 minute arc resolution). Problems of visual accommodation are involved in normal utilization. Various studies have estimated that screen(s)

must be placed anywhere from 20 to 200 ft, as the minimum distance beyond which no eyeball conveyance or focus accommodation can be detected. An advantage is that screens need not be mounted on a motion base, if one is used.

A refractive virtual-image display consists of a real image, on a CRT or other screen, which is projected to infinity by means of an optical system between the viewer and the screen. Another more common approach is to use reflective optics through large-diameter curved mirrors, or some combination of reflective and refractive (Hurd, 1973). Because of the projected visual image, a subject's head must be restricted to a given area, unless "nonpupil" forming systems are used. These systems must be attached to a motion base, if used, because of line-of-sight viewing requirements.

The real-image display, as it is presented on a screen, is characterized by flat scenes and the loss of some depth perception. Unless a very large screen is used, parallax problems are also caused when two operators are involved or when one operator moves his head.

A virtual-image display creates a greater illusion of depth, because of projection of the image to the viewer at infinity. Problems of visual accommodation are also avoided. This display also helps to eliminate the problem of motion parallax when a viewer moves his head, because perspective between two objects is retained (i.e., the objects are viewed at an oblique angle to the projected light rays). Of equal importance, a virtual-image display permits the direct stimulation of other sensors such as night vision goggles and helmet-mounted displays. There is also a possibility that stereoscopic aids can be used with it. One additional advantage is the capability of mixing stimuli from different sources (e.g., CGI) and their projection as a unified scene. For these reasons, a virtual-image display has been selected.

One additional display technique that should be mentioned is a direct-view display, or the direct viewing of a CRT surface. The limited FOV and loss of realism in these displays does not permit sophisticated visual research. But they do offer an important monitoring capability. If virtual infinity displays cannot be effectively provided to two operators, the second operator (pilot or copilot) can view a CRT (or series of CRTs) and still perform coordinated crew activities.

Laboratory Equipment and Controls

Two major requirements impact on laboratory equipment and controls. The first is the calibration and repeatability of experimental conditions. The second is the control, monitoring, and performance assessment of the experiment itself.

Instrumentation techniques and procedures for calibration require special attention. The basic and fundamental value of a visual research facility is the repeatability of the visual or displayed scene in terms of illumination, resolution, and contrast levels. Setting up and controlling these values to a required level, unless planned for, can be a difficult and time-consuming process. The repeatability of a displayed scene will depend, as a minimum, upon the following considerations.

- Light balancing throughout the area of the terrain model,
- The degree to which object surfaces can be made to reflect the desired light level in relation to their background,
- The control of and electronic stability of the sensor and its electronic chain,
- The stability of the ambient light about the viewed display,
- The accuracy and precision of the photometer and radiometers used for the calibration measurements, and
- The care given to the basic adjustments of the TV electronics.

The establishment and demonstration of calibration techniques and procedures to desired tolerance levels will determine the basic validity of a visual research facility.

Control monitoring and performance assessment of an experiment represents the second major consideration. Flexibility of utilization and performance assessment is the key requirement. Minimum needs in this regard include

- Means to establish and initiate experimental conditions;
- Means to modify scenarios, insert new parameter values, reset, or back up an exercise;
- Real-time monitoring or postexercise printout of desired performance values; and
- On-line processing and display of selected information.

The requirements for both of the above areas and their manner of implementation are treated more fully in this report under Test Station Requirements.

Subjects

The type of subjects to be used will influence the requirements for a research facility. The fidelity of aircraft instrumentation and control needed will depend upon the level of the subjects' flight experience. Similarly, the subjects' responses will vary with their background and the type of instrumentation and controls used. The VFRF is intended primarily for qualified helicopter pilots, to obtain representative pilot data, and display and control systems will be designed for this population. However, a proportional control system will be included to permit the use of less-experienced subjects in basic visual studies where pilot proficiency is not a pertinent factor.

PROPOSED RESEARCH PROGRAM

Visual Problem Areas

The laboratory must permit the following functions.

- Visual flight references, or viewing the world through the windscreen with the unaided eye;
- Display reference, or other visual aids that provide visual stimulation; and
- Visual interaction between the real world and a display when the pilot shifts his gaze or transitions from one mode to the other.

These functions are highly interrelated and determine effective pilot performance. They must be considered together in order to assure the validity of the data in each area, as well as a comprehensive research capability. A sample of the type of problems that may be studied in each area follows.

Visual Flight Reference (VFR). Because of low-altitude flight levels and generally less-sophisticated instruments, the helicopter pilot is primarily dependent upon the external visual scene. The external world is also the primary reference by which the pilot maintains or confirms his orientation when using displays. Potential studies can include these:

1. Pilot's visual capabilities under varying illumination levels, backgrounds, and dynamic flight conditions;
2. Primary cues for geographical orientation, and orientation in three-dimensional space;
3. Navigation by terrain features at varying flight altitudes and atmospheric conditions;

4. Obstacle avoidance at varying speeds and illumination levels;
5. NOE flight under normal and low-light levels;
6. Landing and other critical flight maneuvers under reduced visibility;
7. Investigation of "flares" and other artificial illumination aids external to the helicopter;
8. Target acquisition capability (at near recognition thresholds) relative to target type, light levels, and target background;
9. Pilot visual capabilities under fatigue and stress;
10. Flight tactics and procedures for critical time-dependent operations (e.g., pop-up);
11. Fire control studies (e.g., eyeball-directed); and
12. Countermeasure aids and techniques.

Display Reference. Helicopter mission capabilities will be primarily extended through the use of new sensors and displays. Many new display techniques now under development are not limited to the visible light range as are TV, LLLTV, and color systems. These include active illuminators with invisible wavelengths such as lasers, and longer wavelength passive systems such as FLIR. Future helicopter displays will use one or more of these basic wavelengths and may use the combination of active and passive wavelengths when appropriate. New display concepts under development include synthetic color or saturation of the target through special cueing devices; nonliteral displays (e.g., the manner of presenting an IR image); and three-dimensional displays which use dual lenses and independent virtual image projection to each eye. Current state-of-the-art techniques include helmet-mounted devices, night-vision aids, moving target indicators, TV, and LLLTV. The contribution of these systems, their optimum display parameter values, and manner of employment require assessment.

Many independent variables are involved in display research; these include

1. Type and size of symbology and imagery;
2. Superposition and combination of information;
3. Display surface area, i.e., display size;
4. Size of ground to be viewed (i.e., field of view);
5. Nature and detail of terrain features;

6. Target or object characteristics (contrast, size, shape);

7. Flight or search pattern;

8. Aircraft velocity or exposure time;

9. Pilot familiarization or briefing; and

10. Sensor/display characteristics as they affect perception (fidelity of real-world contrast, electronic and optical resolution, bandwidth, and MTF).

The future accommodation of fire-control display studies also warrants consideration. This problem area is more difficult than in fixed-wing aircraft, when one considers the fact that helicopters may have to pop-up, scan a wide area, and shoot in a limited time frame. Potential problems include boresighting, lack of aircraft line-of-sight-to-target, low illumination levels, and cabin vibration. Surveillance from and control of remotely piloted vehicles including helicopters can represent still another long-range problem area. New and sophisticated techniques are also being developed in the area of countermeasures.

Interaction Between VFR and Displays. As noted earlier, the effectiveness of many displays will depend upon the ease with which a pilot can transition between his VFR and his displays and maintain orientation to the viewed scene. This will be particularly true in helicopters, because of low-altitude flight conditions. Several display variables influence this capability:

- Field of view,
- Symbol characteristics,
- Distinctiveness of sky-ground differentiation,
- Clarity and amount of attitudinal reference, and
- Location of display.

This problem area becomes particularly acute under limited time frames and when real-world cues during visual flight reference are reduced, such as during twilight, haze, and night conditions. It is also likely that future helicopter CRT displays will be larger in size than present conventional displays, further necessitating the need for real-world "compatibility" of the displayed scene.

Peculiar Helicopter Display Considerations

In addition to the above categories of study, the peculiar display considerations of helicopter flight will also influence laboratory requirements. Fixed-wing aircraft, due to their normally higher altitudes and long look angles, required high-resolution displays with narrow FOVs. High resolution generally has been obtained at the expense

of a decrease in signal-to-noise (S/N) ratios and loss of contrast sensitivity. Cockpit space limitations dictated small (e.g., 5-in displays. As a result, the small visual angles of the target required high contrast to be seen.

In helicopters, the problem is reversed. The closer proximity to the target or ground means that high resolution is no longer critical. Larger FOVs become important to assure the pilots perspective and orientation. The displayed objects will be larger and, as a result, will require less contrast to be seen. This in turn will place a greater demand on low-contrast sensitivity or rendition in the display. Increased display responsiveness (i.e., frame rates), may also be needed to accommodate for the higher angular viewing rates.

Engineering development in the past has focused on the increase of display resolution in small displays. Helicopters may need larger CRT displays with good contrast rendition. The short viewing ranges of helicopters may also meet the geometry requirements of three-dimensional displays. Such displays can aid depth perception and may aid in camouflage breaking. The stereo-power and information provided by such displays may also be increased through the use of different filters and sensors for each optical unit. The above considerations will influence laboratory requirements for necessary optical or lens systems, power supplies, bandwidths, CRT sizes, and hookups.

The display research conducted in the proposed laboratory should contribute to the effectiveness and importance of visual and fire control aids. These, in turn, will represent the focal points about which future helicopter cockpits will be designed. At present, many of these considerations have low priorities, from the engineer's perspective.

Program Areas

Based on the foregoing, the proposed research program is defined as follows.

1. Plan and conduct applied research designed to increase the understanding, enhancement, and utilization of helicopter pilot skills during NOE flight.

2. Perform research to define individual and team performance capabilities and limitations in situational and operational contexts, including the effects of stress, workload, and error causative factors.

3. Develop pilot performance standards, criteria, and measures of effectiveness in system operation.

4. Investigate the pilots' dynamic visual capabilities and requirements for new sensor-display aids.

5. Evaluate new concepts, aids, and procedures for navigation and fire control.

6. Integrate and assess the performance of multiple crew functions under varying environmental and time constraints in crew station design.

7. Supplement, coordinate, and validate research activities with helicopter flights in the operational contest.

The program areas to be addressed are

- Visual capabilities,
- Visual aids/sensors,
- Display parameters,
- Pilot proficiency,
- Crew coordination,
- Navigation, and
- Cockpit layout.

The following sections illustrate the types of problems and system variables to be addressed in each area, including the primary dependent variables.

Visual Capabilities. Perform research to determine the pilot's basic dynamic visual capabilities during NOE flight, including

- Depth perception,
- Acuity (wire),
- Terrain feature discrimination (texture and color),
- Target acquisition (at near recognition thresholds),
- Target tracking, and
- Spatial orientation and reduction of vertigo.

Investigate influences of the following system factors on the above-listed capabilities.

- Varying illumination levels and artificial light sources;
- Effects of high angular visual velocities;
- Environment--haze, sun, night;
- Visual workload; and
- Pilot scan patterns.

Visual Aids/Sensors. Investigate new techniques, concepts, and procedures to aid and augment pilot visual capabilities under day and, particularly, night conditions, including consideration of

- New design approaches and concepts,
- Visual requirements and design criteria,
- Real-world correlation and interaction with displayed scene,

- Helicopter control (descent, landing),
- Depth perception, and
- Target acquisition.

Investigate influences of the following system factors on the above goals.

- Special devices, e.g.,
  - heads-up display,
  - helmet mounted display,
  - night-vision goggles, and
  - stereoscopic aids.
- Special sensors in the visible and invisible light ranges, e.g.,
  - FLIR,
  - LLLTV, and
  - sensor combinations.

Display Parameters. Determine optimum display parameters for helicopter NOE flight under day-night and all weather conditions.

- Display size,
- Display location (e.g., overhead),
- Display contrast rendition,
- FOV,
- Information content,
- Real-world compatibility,
- Symbology, and
- Display adjustments.

Investigate influences of the following system factors on the above objectives.

- Operating conditions,
- Mission phase,
- Cockpit layout and lighting, and
- Information requirements.

Pilot Proficiency. Perform research to determine basic pilot capabilities in the NOE operating environment, including such considerations as

- Baseline standards,
- Performance criteria,
- *Measures of effectiveness*, and
- Endurance/performance decrement.

Investigate influences of the following system factors on the above objectives and develop techniques and operating procedures to minimize fatigue and performance degradation.

- Environment,
- Mission phase,
- Equipment,
- Training and experience,
- Selection,
- Individual/team performance, and
- Workload.

Crew Coordination. Investigate procedures, techniques, and aids to improve crew coordination and to optimize crew effectiveness, including consideration of

- Workload distribution,
- Worksharing techniques and procedures,
- Communication procedures,
- Error causative factors and development of preventative techniques, and
- Optimum workload.

Investigate influences of the following system factors on the above goals.

- Crew location,
- Personality factors/attitudes,
- Special aids and devices,
- Training,
- Leadership,
- Environment, and
- Mission phase.

Navigation. Perform research on new aids, techniques, and procedures to improve pilot/copilot navigational skills, including

- Terrain analysis,
- Geographical orientation,
- Recognition of checkpoints,
- Mission time, and
- Coordination with forward observers.

Investigate influences of the following system factors on the above goals.

- Maps,
- Map displays,

- Navigation aids,
- Flight planning,
- Dead reckoning,
- Visibility,
- Display FOV,
- Helicopter speed,
- Training,
- Terrain characteristics and checkpoints, and
- Teamwork.

Cockpit Layout. Investigate optimum cockpit design parameters for ease of visual performance and crew coordination during NOE flight, including

- Cockpit lighting (dark adaptation),
- Minimization of sun glare,
- Panel arrangement/display location,
- Cockpit geometry/anthropometrics,
- Standardization of locations,
- Location of pilot's seat (visual line-of-sight), and
- Crew comfort.

Investigate influences of the following system factors on the above objectives.

- Workload,
- Crew location,
- Environment, and
- Information requirements.

FUNCTIONAL REQUIREMENTS

Functional specifications generally refer to the comprehensive functions or operations essential for the accomplishment of stated goals, within defined constraints such as environment or budget. Performance requirements represent another level of detail and contain quantitative values and tolerance limits. The latter information requires the benefit of additional analysis (feasibility studies and trade-off analyses).

This section presents the basic functional requirements for the VFRF. The resulting system specification and performance requirements for the VFRF are contained in King (1975). Some performance values are given below for illustration purposes.

As discussed previously, a laboratory facility is designed for simulation of visual, sensor, and environmental variables and their interaction for a variety of direct visual and aided visual studies with E-O and infrared (IR) sensors. The facility must have sufficient flexibility to accommodate a wide range of visual systems and combinations. The system will be used in the ARI Aircrew Performance research

program for NOE research, as described in the preceding section. The functional requirements to meet these goals encompass the following areas and are discussed below.

- Night visual requirements,
- Day visual requirements,
- Motion requirements,
- Terrain table requirements,
- Sensors and visual aids,
- Displays,
- Cockpit,
- Environmental requirements, and
- Calibration and control.

The contents of a visual cue analysis which assisted in the determination of the visual requirements are shown in Appendix C. Motion picture films using a wide-angle lens were taken from a helicopter to investigate some of the variables. Black and white as well as color films were used. Pictures were also taken from the jump seat to record pilot head motions and eye movement as reflected by a section of a spherical mirror placed on the center support structure of the windscreen. The results of these analyses are reported in the following and appropriate sections of the report.

During the following discussion on visual requirements, all light values are expressed as foot-lamberts (FL). When necessary and for convenience, millilamberts (mL) are converted 1:1 to FL, since 1 mL equals .929 FL. Foot-candles are also converted to foot-lamberts, since foot-lamberts are the "equivalent derivation of foot-candles" (Kuehn, 1968). Visual resolution values are specified as subtended angles in terms of minutes of arc. TV resolution is based on a TV line pair, as usually obtained from a resolution chart. Optical resolution is based on a line pair such as found in a bar chart. The 1951 Air Force resolution chart, or the resolution chart of the National Bureau of Standards (NBS), is the usual reference. The monochromatic visual display proposed by the Martin Marietta Corp. has 8 arc min for a TV line pair, which gives an effective display resolution of 5 arc min for a single line. The rationale for this is explained in Appendix D.[4]

Night Visual Requirements

The following considerations are important for establishing the appropriate display parameters for night viewing.

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[4] Prepared by Mr. J. Ohmart of the Martin Marietta Corp., who also assisted with this section.

- Night illumination range,
- Visual resolution capabilities within this range,
- Variation of visual resolution with scene contrast, and
- Effect of dynamic image scenes on visual resolution.

Illumination Range. Most visual data for daylight viewing start at 1 FL (e.g., see Figure 14). As shown in Figure 5, this light level represents dusk, just before sunset. The eye's ability to compensate, or the phenomenon of apparent brightness, makes this level appear brighter than it is. In this respect, most simulated visual displays or movie screens are close to this level (e.g., 1-5 FL). Thus, while 1 FL would be a desirable starting point for a night system, it would be too close perceptually to daylight viewing conditions. Figure 5 also shows that with sunset and full moon conditions, the light level drops to .1 or 10^{-1} FL. For night NOE flight, this level appears to be an appropriate starting point and baseline flight condition. Cone and rod vision are still active at this level. A consensus of the data appears to place rod vision alone, starting at light levels about 4×10^{-3} (e.g., Figure 6), with full night vision starting at 10^{-2} (Figure 5).

Figure 5 shows 10^{-6} FL as the lower limit for night vision, and as the rod threshold for the dark-adapted eye. Figure 6, however, shows that the practical limits of visual acuity are reached at 10^{-5} FL. This light level represents a condition between snow in starlight and snow on an overcast night (Wulfeck, 1958). As a result of the above considerations, it is reasonable to establish the illumination range for night NOE between 10^{-1} and 10^{-5} FL. Unlike day viewing conditions, where the phenomenon of "apparent brightness" operates, the light values in this range must be provided in a one-to-one fashion.

Visual Resolution Capabilities. The resolution capability of the eye at 10^{-1} FL is 1.2 arc min (Figure 6). This value is based on high contrast targets. The numerical value would increase (i.e., the resolution capability would decrease) if adjusted for lower contrast values as found in the real world (Table 2). At 10^{-3} FL, the resolution capability of the eye is reduced to 10 arc min. Because of the rapid change of visual capabilities with illumination in this lower light region, a more reasonable visual resolution requirement would be 3 arc min. This would correspond to 10^{-2} FL, at which point night conditions begin.

As noted above, the effective resolution of the proposed visual display will be 5 arc min. This means that the display will be eye limited when the visual resolution requirement is greater than 5 arc min and will be display limited when the visual resolution requirement is smaller than 5 arc min (e.g., 1.2 arc min at 1 FL). The crossover point in the illumination range between an eye- and a display-limited windscreen presentation relative to a display resolution of 5 arc min is 7×10^{-3} FL (Figure 6).

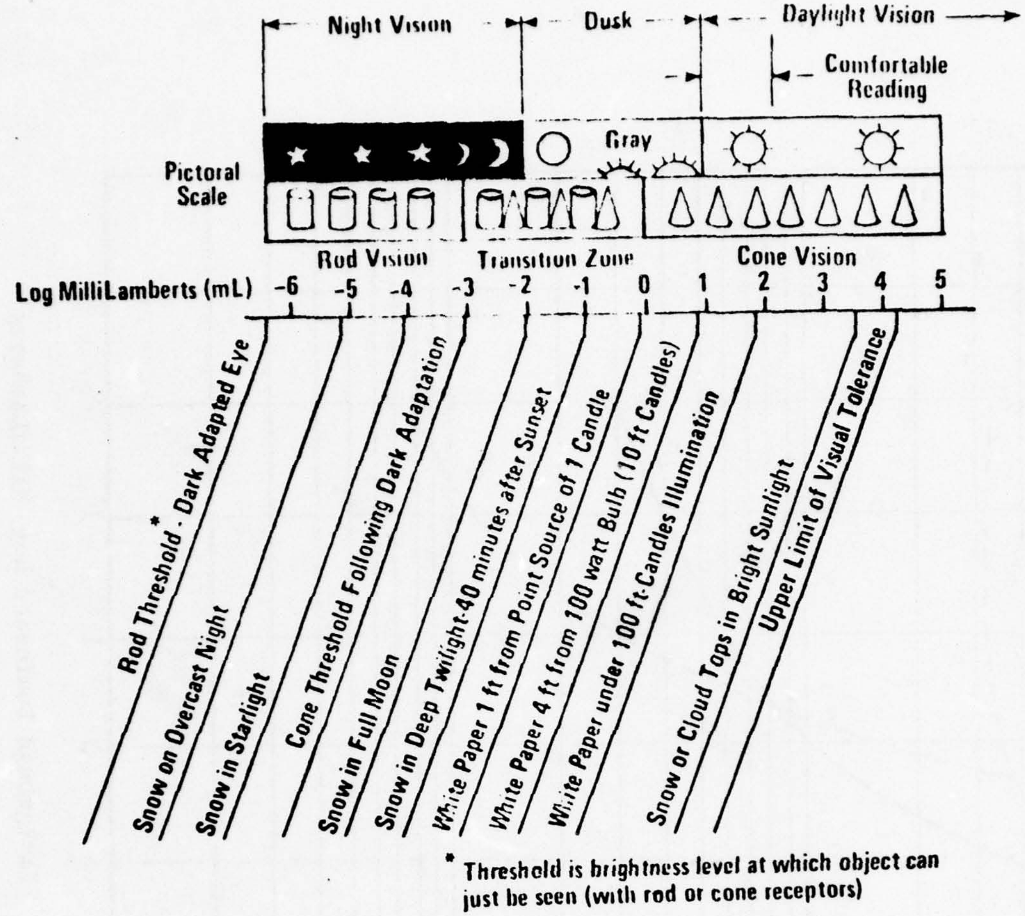


Figure 5. Luminance under various natural conditions of illumination (from Wulfeck, 1958).

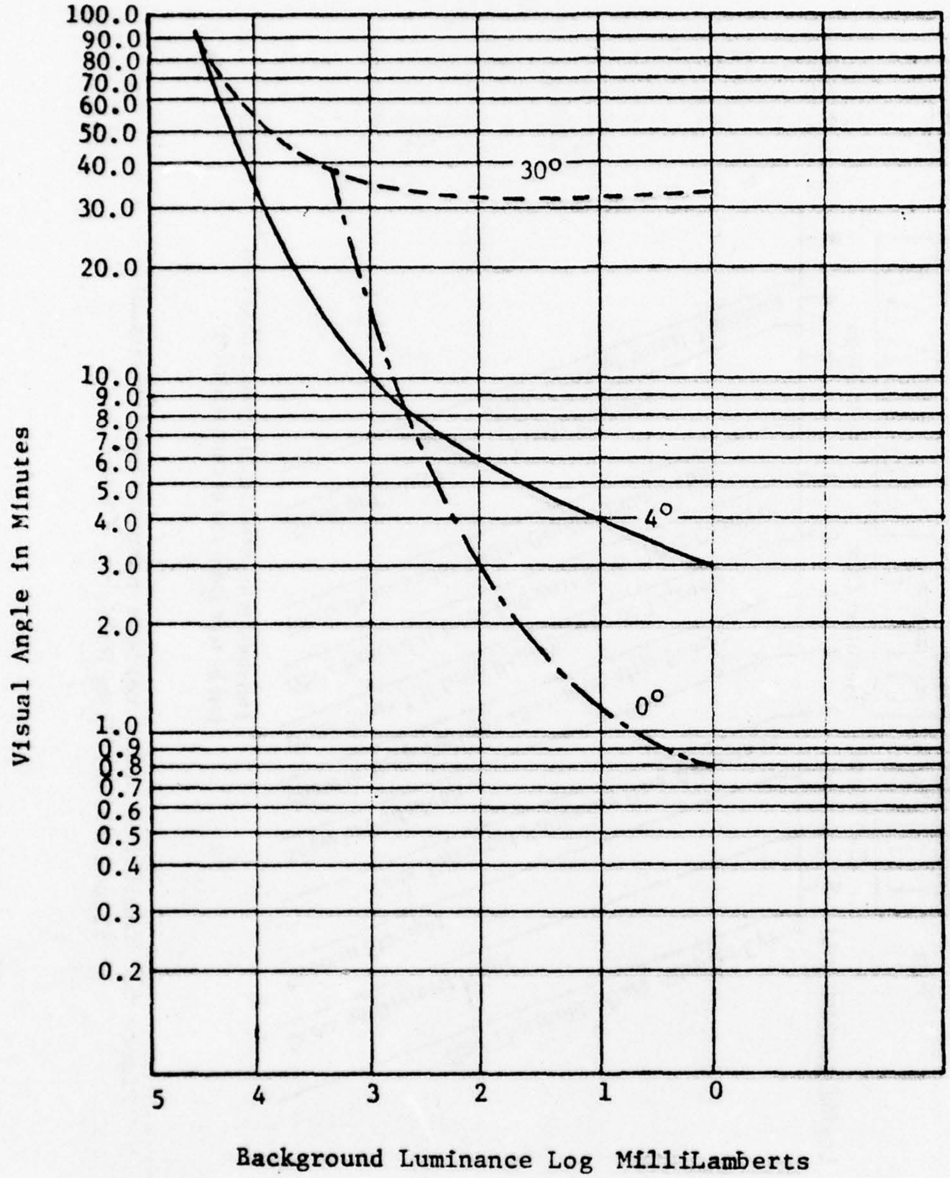


Figure 6. Visual angle of smallest discriminable detail as a function of background luminance (from Wulfeck, 1958).

Table 2

Visual Resolution Relative to Contrast and Illumination

Illumination (FL)	Contrast 92.9%	39.4%	24.4%
10^{-1}	1.2	2.2	2.5
10^{-2}	2.8	5	10
10^{-3}	6.6	16	33

In Figure 6, visual acuity is shown for both the fovea and the off-axis angular distance from the fovea (e.g., 4° and 30°), due to the take-over of rod vision at about 4×10^{-3} FL. Thus, rod and cone vision are operating at the abovementioned foveal crossover point of 7×10^{-3} FL. When tie display is viewed 4° off axis, a visual capability of 5 arc min is achieved at approximately 4×10^{-2}.

With foveal viewing alone, the light range above 7×10^{-3} represents approximately 32% of the total light range which is display limited. When viewing at 4° from the fovea is considered, only 14% of the total light range is display limited. The true threshold may lie between these two values, on the premise that the line of regard should be shifting between them, due to the lower light levels and fewer cones involved. 7×10^{-3} FL, however, will be used as the reference point at which the display becomes eye limited with decreasing light levels (i.e., 68% of the light range). Figure 5 shows that this light region represents the major portion of night vision starting approximately below half-moon conditions.

Note that color vision can still theoretically operate down to 4×10^{-3} levels of illumination and is readily apparent in dusk conditions between 10^{-1} and 10^{-2} FL. Pilots have also reported that color vision is not entirely lost during night flight, with greens and some browns being visible. As a result, the lack of color in this region will detract from the realism of the display as well as its apparent contrast. Its effect within this narrow light range cannot readily be determined. A night presentation was viewed at NASA (Ames) on a 20-inch Conrac monitor with a large, two-element lucite lens interspersed between the CRT and the viewer. This lens magnified the scene and gave the impression of infinity. Both color and black and white scenes were presented. The color presentation appeared to be more realistic due to greater apparent contrast. This effect may be minimized with the higher

quality, virtual-image displays proposed or may have to be accounted for in terms of an effective loss in light value.

Visual Resolution Capabilities When Adjusted for Contrast. The above resolution values were based on maximum contrast levels (e.g., 95%-100%). Contrast values on the earth, however, vary from about .03, for damp earth to .9 for fresh snow. Average overall contrast is approximately .39^{o} (Buddenhagen, 1961). The contrast for NOE-type terrain, heavily treed areas and open fields, should average about 24%, particularly when one considers the uniform density of trees. The average contrast level of the terrain table can be established at this level, in this report, with no loss in research validity. The visual capability of the eye drops appreciably with contrast levels as well as illumination values. Figure 7 shows the variation in visual resolution with contrast.

Resolution values associated with the contrast values, as interpolated from Figure 7, are shown in Table 2. The values are assumed to be for foveal vision, since Figure 7 does not make a distinction between foveal and off-axis viewing. From Table 2, it can be seen that the illumination value associated with 5 arc min starts at 10^{-2} FL for 39.4% contrast and approximately 5×10^{-2} for 24% contrast.

The illumination crossover point relative to a visual display resolution of 5 arc min is summarized in Table 3, for the range of contrast values discussed above. It is apparent that the illumination threshold values shift to the right as contrast levels are reduced. It should be noted that the threshold for 24% contrast is comparable to the threshold for high-contrast targets when viewed 4^{o} off-axis. In view of this comparability, it would appear reasonable to set the light threshold value at 4×10^{-2} as the approximate light level where 5 arc min resolution is achieved, whether with rod vision (off-axis viewing of high-contrast targets or more direct viewing of low-contrast targets). This threshold value would account for 85% of the light range where the display will be eye limited.

Table 3

Illumination Threshold Values Relative to Visual Angle of 5 Arc Min and Contrast

	Contrast		
Viewing angle	95%	34.4%	24.4%
Fovea	7×10^{-3}	10^{-2}	5×10^{-2}
4^{o}	4×10^{-2}	--	--

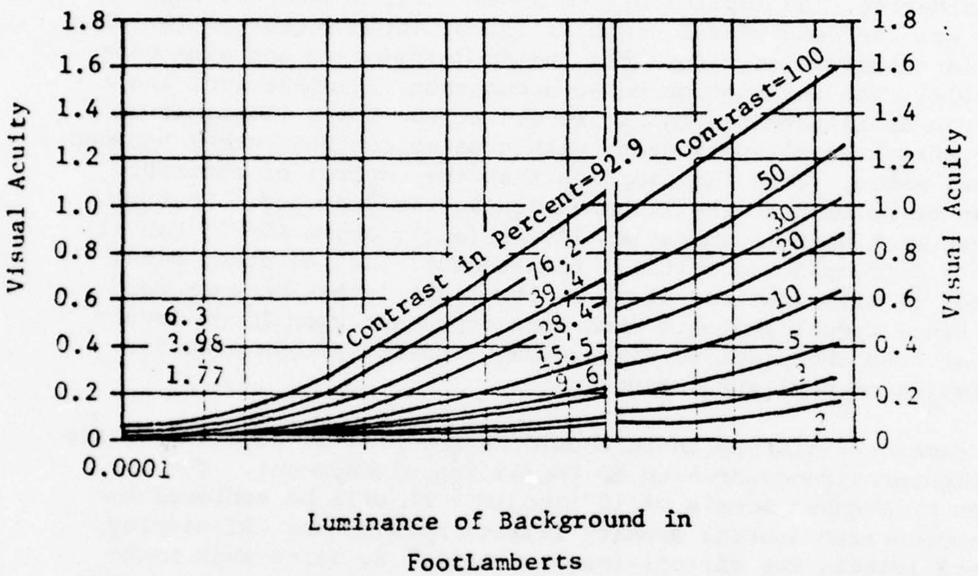


Figure 7. Visual acuity as a function of contrast (from Wulfeck, 1958).

If the 34.4% contrast value is used, the light threshold falls to 10^{-2}, which is the beginning of full night vision (Figure 5), although still above the rod-cone crossover point of 4×10^{-3}. At this value, 75% of the light range will provide an eye-limited display. This latter value will represent a more conservative reference point. Thus, when resolution values are adjusted for contrast, the eye-limited portion of the display increases to 75% from 68% (i.e., from 7×10^{-3} to 10^{-2} FL). The area of night vision starting just after dark, with less than full moon conditions (i.e., 10^{-2} to 10^{-5} FL), will represent the primary area of interest for night NOE studies and represents the critical area where sensor aids will be used.

The implications of contrast control during simulation are also worth considering. As implied by the above data, higher contrast is needed to see the same visual angle as illumination decreases (or with decrease in illumination visual resolution degrades at the same contrast level). The interaction between contrast, illumination, and visual angle is illustrated in Figure 8. At the lower illumination levels, contrast sensitivity drops with greater contrast steps between each visual angle. This fact implies that the control of contrast levels can be relaxed at the illumination levels proposed. Control of contrast at higher illumination levels (e.g., above 10 FL) has always been a difficult and critical requirement. On the other hand, the control of illumination values at low light levels becomes more critical since visual angle is much more dependent upon light levels as apparent from the previous discussion. The reverse is true for the simulation of daylight scenes.

The camera-TV display chain should have a log. 10 step gray scale over a brightness range of 5 to 50 FL (at the windscreen). The low windscreen brightness levels of 10^{-1} to 10^{-5} FL will be achieved by placing appropriate neutral density filters between the CRT display and the eye (within the virtual-image system). By using this technique, no system degradation will take place by forcing the TV system to operate at low S/N ratios due to low-light levels.

Impact of Angular Velocities. The impact of angular velocity on the resolution capability of the human eye must also be taken into account. As shown in Figure 9, appreciable degradation occurs at angular velocities of 20 deg/sec, particularly at lower light levels such as 10^{-1} and 10^{-2} FL. For example, a visual resolution capability of 1.2 arc min at high-contrast levels and under 10^{-1} FL of illumination (Table 2) will degrade to 4 arc min at 20 deg/sec angular velocity and to approximately 5.2 arc min at 50 deg/sec angular velocity. In this respect, the loss of visual resolution is proportionally greater to increased angular velocity than it is to lower contrast values as shown in Table 2. Angular velocity and lower contrast values should also interact to produce even greater visual degradation. However, data are not available to show this interaction.

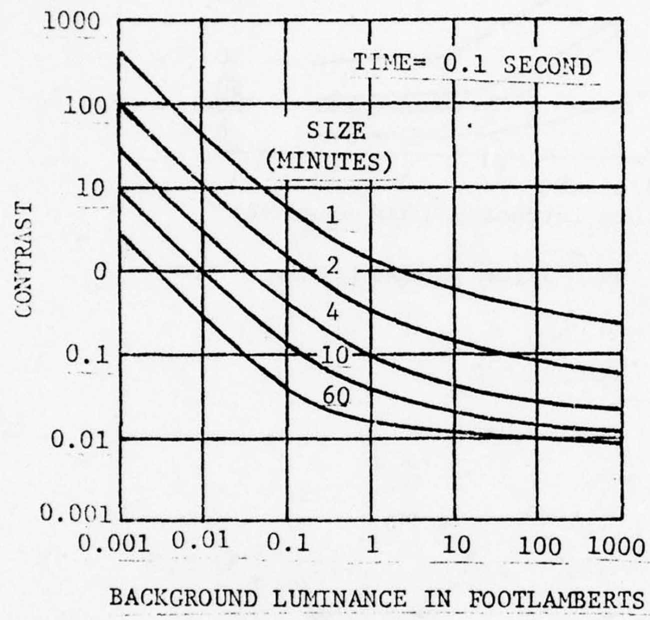
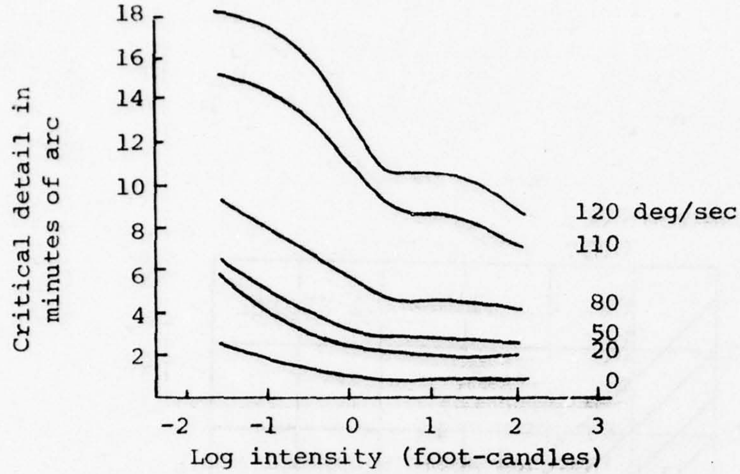
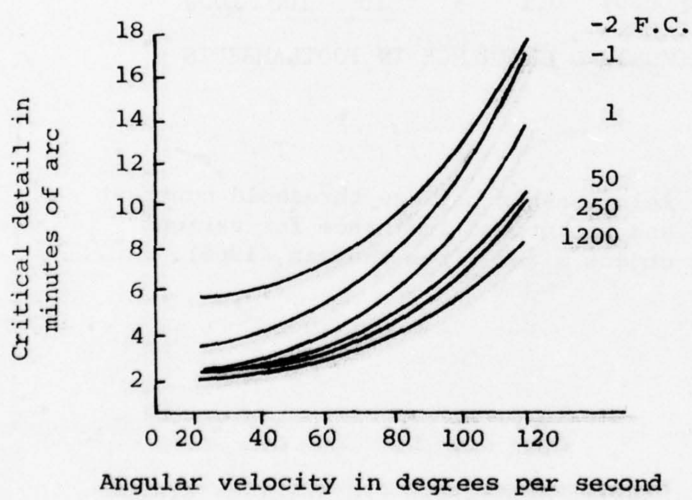


Figure 8. Relationship between threshold contrast and background luminance for various object sizes (from Kaufman, 1966).



9a. Illumination level.



9b. Angular velocity.

Figure 9. Acuity as a function of (a) illumination level and (b) angular velocity (from Miller, 1958).

The potential ranges of angular velocities at aircraft velocities between 5 and 60 knots are shown in Table 4. In this table, the pilot's line of sight is 90°, so that 85° represents 5° from this axis. In some cases, the same values are obtained for two angular deviations (e.g., 30° and 50°).

As Table 4 shows, angular velocity increases with speed, angular deviation, and reduced viewing range (decreasing "R" values). At night, NOE velocities will be about 20 knots.[5] The pilot's maximum viewing angle will be about 40°. For an "R" value of 200 and 400, the viewing range will equate to approximately 240 ft and 480 ft[6] respectively. These latter values represent realistic viewing ranges, under no-moon conditions. The associated angular velocities with these conditions are 3.64 and 1.82 deg/sec, respectively. (These angular velocities double at twice the airspeed.) A 40° viewing angle represents a worst-case condition. As angular deviation decreases from 40°, the drop in angular velocity is rapid, with 3.64 deg/sec representing the worst case at the viewing ranges selected. At closer viewing ranges, such as 60 ft to 120 ft,[7] and at the same angular deviation and airspeed, the angular velocity increases to 14.6 and 7.3 deg/sec, respectively. At these closer viewing distances, however, aircraft velocity would be much slower.

An angular velocity of 3.64 deg/sec, at a viewing range of 240 ft (or probable worse case), will only lead to a degradation of visual resolution of less than .5 arc min at 10^{-1} FL. As a result, visual degradation due to angular velocities should be minimal during night NOE. Any degradation that may occur will tend to shift the light threshold value farther to the right, making a still higher percentage of the display eye limited. As a minimum, it increases the validity of the threshold value selected (i.e., 10^{-2} FL).

<u>Practical Implications of 5 Arc Min Visual Resolution</u>. As noted above, a display resolution value of 5 arc min leaves approximately 25% of the display above 10^{-2} FL as display limited. The practical implications of this limitation at NOE altitudes may be minimal because of the relatively short viewing ranges involved. The pilot scans approximated 500 to 1,000 ft during daylight conditions, with an occasional scan to 1,500 to 3,000 ft at an average flight speed of 40 knots. At night, the speed range drops to about 20 knots with a viewing range between 250 and 500 ft. The impacts of these closer viewing ranges,

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[5] See section on Characteristics of Nap-of-the-Earth Flight.

[6] When divided by the tangent of the viewing angle, to solve for the base of the triangle or viewing range.

[7] Calculated from "R" values of 50 and 100 ft.

Table 4

Angular Velocity as a Function of Distance "R" From the Tangent of the Target to the Flight Path, and the Angle from the Flight Path Normal to the Target

Angle to target	Velocity, MPH	Distance "R" in feet					
		50	100	200	400	800	1500
85°	5	.73	.36	.18	.09	.04	.02
	10	1.46	.73	.37	.18	.09	.05
	20	2.92	1.46	.73	.36	.18	.09
	40	5.84	2.92	1.46	.73	.36	.19
	60	8.76	4.38	2.19	1.09	.55	.29
80°	5	1.43	.72	.36	.18	.09	.05
	10	2.87	1.44	.72	.36	.18	.09
	20	5.75	2.87	1.44	.71	.36	.18
	40	11.50	5.70	2.87	1.44	.72	.36
	60	17.40	8.70	4.35	2.17	1.08	.57
70°	5	2.70	1.35	.67	.33	.16	.09
	10	5.40	2.70	1.35	.67	.33	.18
	20	10.80	5.40	2.70	1.35	.67	.36
	40	21.60	10.80	5.40	2.70	1.35	.72
	60	32.41	16.20	8.10	4.05	2.03	1.08
60°	5	3.64	1.82	.90	.45	.22	.12
	10	7.27	3.64	1.82	.90	.45	.25
	20	14.60	7.30	3.64	1.82	.90	.48
	40	29.10	14.60	7.30	3.64	1.82	.97
	60	43.70	21.80	10.90	5.50	2.73	1.46
50°	5	4.14	2.07	1.03	.51	.26	.14
	10	8.27	4.14	2.07	1.03	.51	.28
	20	16.54	8.27	4.14	2.07	1.03	.55
	40	33.10	16.54	8.27	4.14	2.07	1.03
	60	49.65	24.80	12.40	6.20	3.10	1.66

relative to different object sizes and visual resolution limits, have been plotted in Table 5.

Table 5 (which assumes high-contrast objects) shows that with 5 arc min resolution, a 4.5-inch-wide object detail can be resolved to 250 ft. A 9-inch-wide object can be seen up to 500 ft, and an 18-inch object (which is about the width of a large man) can be seen up to 1,000 ft. A tank would be just resolvable at approximately 10,000 ft. Thus, in the region of dusk and full-moon conditions, at 250- to 500-ft viewing ranges, objects of 4.5 inches to 9 inches in width would be discernible. These sizes can represent large leaves, limbs, and tree trunks. Details of this size and larger tree shapes and ground objects would be discernible. In effect, although display limited at this upper light region, the display still would have some practical research value.

Brightness Adaptation. As noted earlier, illumination control becomes a critical consideration during the simulation of night scenes. Corresponding to this requirement is the importance of a subject's dark adaptation to assure his appropriate visual response at the light levels simulated. In this respect, lighting control in the cockpit also becomes an important consideration, as well as a potential experimental parameter. Figure 10 shows the adaptation time for a 2^{o} target. Larger objects, e.g., 5^{o}, would have lower adaptation thresholds (Smith, 1966). It is evident from this figure that the fovea adapts quickly, but that the rods require appreciably more time. The dotted lines show the effect of high- and low-illumination levels before adaptation begins. Length of exposure to initial light conditions is also a determining factor. As the brightness drops, the iris opens wider and the rods gradually take over from the cones. The diameter of the iris varies roughly between 3 mm and 6 mm, depending upon the age of the subject (Smith, 1966) and may serve as one test of dark adaptation.

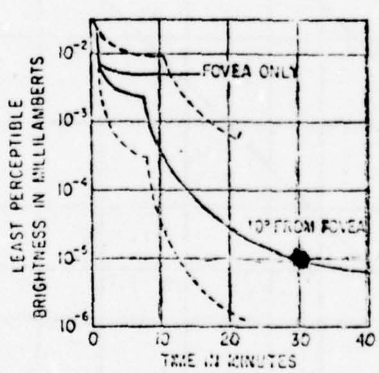
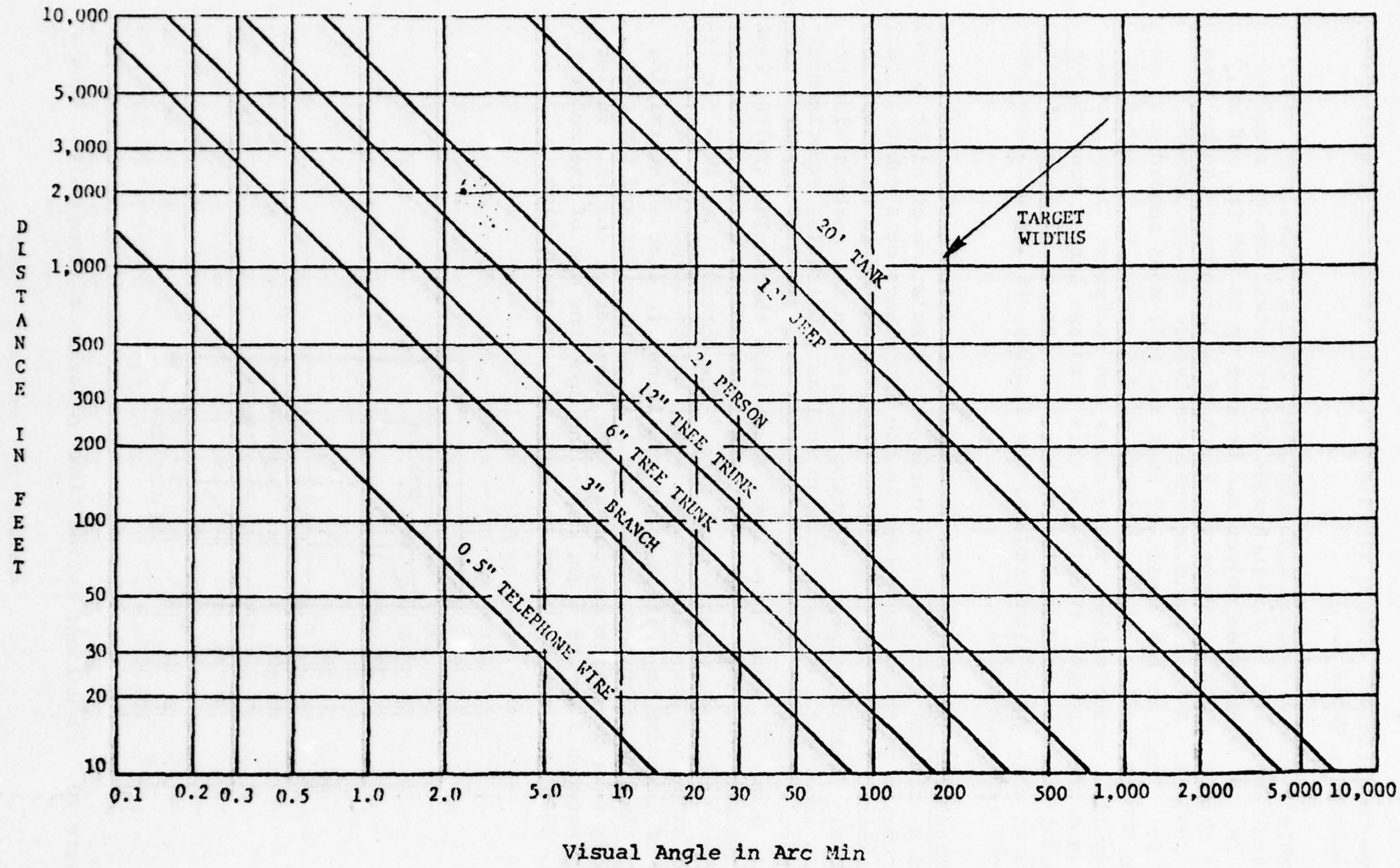


Figure 10. Visual adaptation time to darkness (from Smith, 1966).

Table 5

Target Distance Versus Subtended Visual Angle



Field of View (FOV). The visual FOV is also an important consideration. During high-altitude flight, the pilot generally scans a limited field of view at a considerable slant range from the aircraft (e.g., 10 to 40,000 ft). During NOE flight, the pilot's viewing range is roughly 50 to 4,500 ft. This fact, plus the lower flight speeds both require and permit the NOE pilot to scan a larger FOV. A 120° FOV is almost the minimum the pilot must scan to adequately survey the scene immediately in front of his windscreen. A 120° FOV is also consistent with a person's normal viewing area. There is also some evidence that the lack of peripheral vision in a normally wide FOV situation could induce uneasiness due to the lack of general altitudinal reference that is acquired through peripheral vision.

The pilot has a vertical FOV of approximately 55° in the UH-1H. Of this, at least 30° to 40° represents the primary viewing envelope. The FOV presentation below his normal line of sight should be somewhat larger than the FOV above his line of sight, because the pilot tends to shift his gaze somewhat downward during NOE.

Special Effects. Night overcast conditions must also be considered, which will affect visibility in terms of both illumination and contrast. Lunar glare also represents an important consideration, with pilots reporting adverse effects due to shadows and night blindness, and the necessary dark adaptation involved in getting into and out of displays.

Simulated light sources will also be of value on the terrain, to add realism to small villages. Simulation of overhead wires should also be considered. The latter two considerations, however, may be difficult to simulate due to raster scan limitations, such as blooming of lights or necessary resolution for wires, as well as problems of dynamic range of the electronic subsystems when simulated light sources are added. Special supplementary image-generation techniques may have to be employed--e.g., beam splitters, CGI, or projection by computer overlay.

In summary, an illumination range of 10^{-1} to 10^{-5} FL is required as the representative and useful range for simulated NOE flight at night. This light range will vary from dusk to starlight conditions. A visual display with a resolution of 5 arc min will permit valid visual experiments between the illumination range of 10^{-2} to 10^{-5} FL, because the resolution capability of the eye is poorer than this value at these light levels. This light region represents the primary light region under which night NOE will be conducted and where special sensors and visual aids will be employed. In the remaining light range, 10^{-1} to 10^{-2} FL, human visual resolution capabilities are better than 5 min of arc. This represents the light range associated with dusk, just after sunset, and during full moon. The effect of this display limitation is minimized, however, in view of the factors mentioned above, which reduce or negate high-resolution requirements. The lack of color in the limited region of 10^{-1} to 10^{-2} FL represents a potential loss of realism.

Day Visual Requirements

The following primary variables must be addressed to assure the simulation of a visual display that will permit valid daylight psychophysical studies:

- Maximum illumination range for effective visual acuity,
- Display resolution comparable with real world (i.e., NOE) acuity requirements,
- Realistic scene contrast,
- Appropriate visual cues for depth perception and visual perspective, and
- Simulation of a reasonable spectrum of chromatic cues.

The requirements in these areas are discussed below.

Illumination. In most visual display systems, "apparent" brightness is generally sufficient for the intended objectives (e.g., training). At the display scene, 4 to 5 FL of illumination is adequate to provide an "apparent" daylight scene. At this light level, however, a subject's visual acuity is reduced. Figure 11 shows the relationship between visual acuity and light levels. Near maximum visual acuity occurs at about 100 FL, where the scope of the subsequent improvement begins to level off. According to Buddenhagen (1961),

> Even though we must grant that visual acuity continues to increase beyond this luminance level, it is apparent that the sensory response of the human eye and the related perceptual response of the human observer changes very little. In terms of perceptual fidelity, it may be concluded that visual fields with more than 100 millilamberts luminance are approximately perceptually equivalent, and that relative to visual acuity, a simulation display technique that is capable of generating 100 millilamberts, possesses almost 100 percent perceptual fidelity.

The practical implication of higher illumination levels for simulation was evaluated by Harris (1974) relative to the influence of illumination on probability of detection at varying viewing ranges. Figure 12 shows the probability of detection when illumination and viewing range are taken into account. It shows performance to be comparable or identical at 100 and 50 FL, chiefly because, with reduced illumination, performance is lost primarily at the more distant ranges and less at the more close-in ranges.

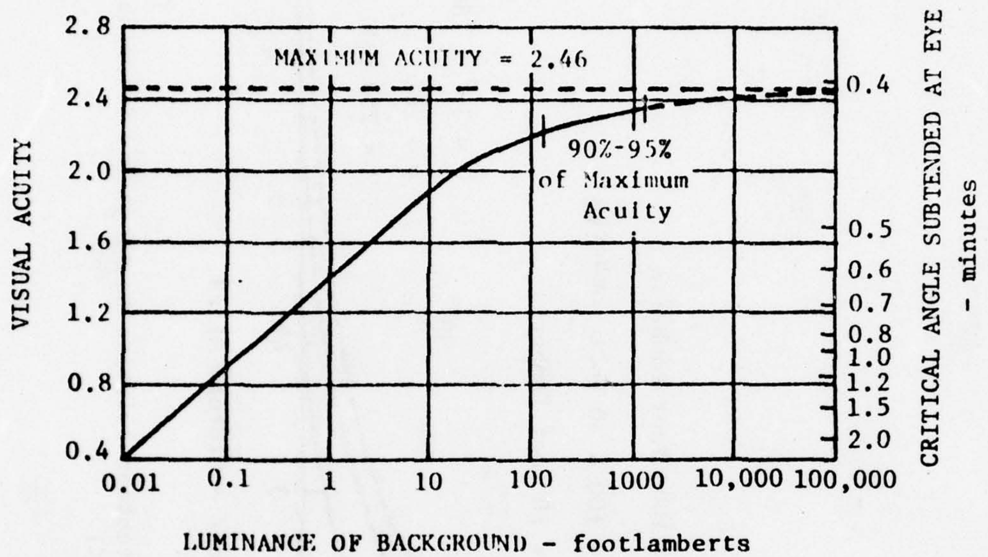


Figure 11. Variation in visual acuity and visual size with background luminance for a black object on a white background (Kaufman, 1966).

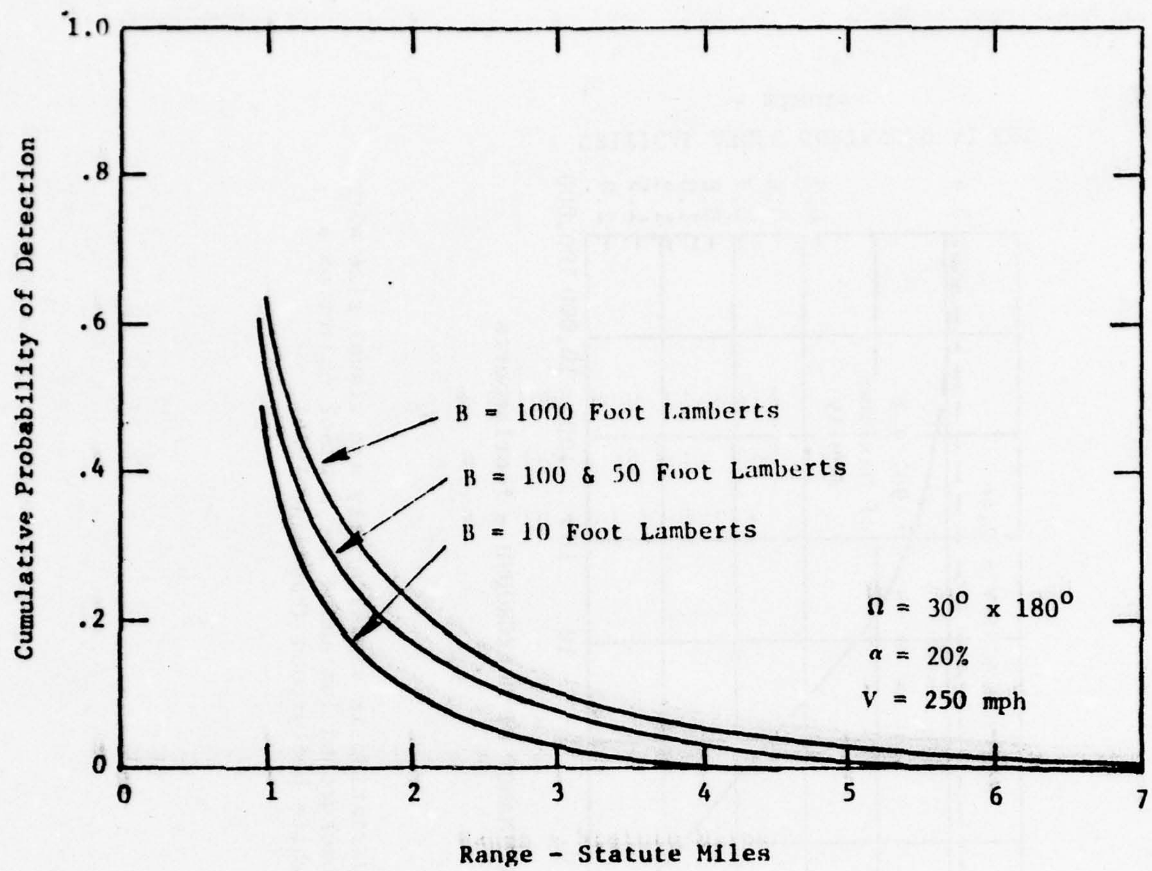


Figure 12. Probability of detection relative to range and illumination (from Harris, 1974).

Harris states that

> The acceptable tolerance in scene luminance depends upon the specific experiments to be performed and the precision desired in the experimental results. It would be expected, however, that differences in performance between 50 FL and 100 FL scene luminance will be lost in the noise of individual differences and other experimental factors.

Thus it would appear that maximum luminance levels can be less than the desirable 100 FL relative to specific experimental conditions. However, 100 FL represents the ideal requirement.

Visual Resolution. Visual resolution may be defined as the ability to distinguish fine detail. This capability can be expressed as (a) visual angle or (b) visual acuity. Visual angle is a function of the physical size of an object (or its minimum separable features) and its distance from the point of observation. By combining these two dimensions, one can express the perceived dimension as a visual angle which usually is measured in minutes of arc. Thus, the farther a given object is from the eyes, the smaller its visual size and visual angle become.

The ability of an individual to see two portions of the visual field as spatially separated is called visual acuity and is based, in part, upon the resolving ability of the retinal mosaic. Visual acuity is defined as the reciprocal of the minimum effective visual angle in terms of minutes of arc. This makes higher numerical values reflect higher degrees of excellence in visual acuity, with an expanded scale ratio for smaller objects. Visual angle, as a result, is a more convenient measure to use to express visual resolution.

Visibility, while influenced by the same factors as visual acuity or visual angle, is more synonomous with the detectability of an object than the minimum separability of its features. For this reason, the visibility of an object is superior to a person's capability to resolve its detail. Hecht and Mintz (1938) found that a single line on a homogeneous background of considerable extent could be seen when it subtended a visual angle of only .05 second of arc. This is roughly equivalent to seeing a wire 1/16-inch in diameter, half a mile away. The retinal image produced by a target subtending an angle of this size is actually smaller than the diameter of a single cone. Similarly, a star is too small to measure in terms of its actual visual angle. However, apparent size, or magnitude, is the result of scatter within the eye and the brightness of the source object.

Basic human visual resolution is generally accepted to be 1 arc min. In this respect, the visual resolution chart is referenced to a 1 min of arc visual capability (i.e., 20/20 vision). Visual resolution, however, varies considerably, with contrast and luminance as shown in Figure 13, and with position on the retina, in terms of distance from the fovea, as shown in Figure 14.

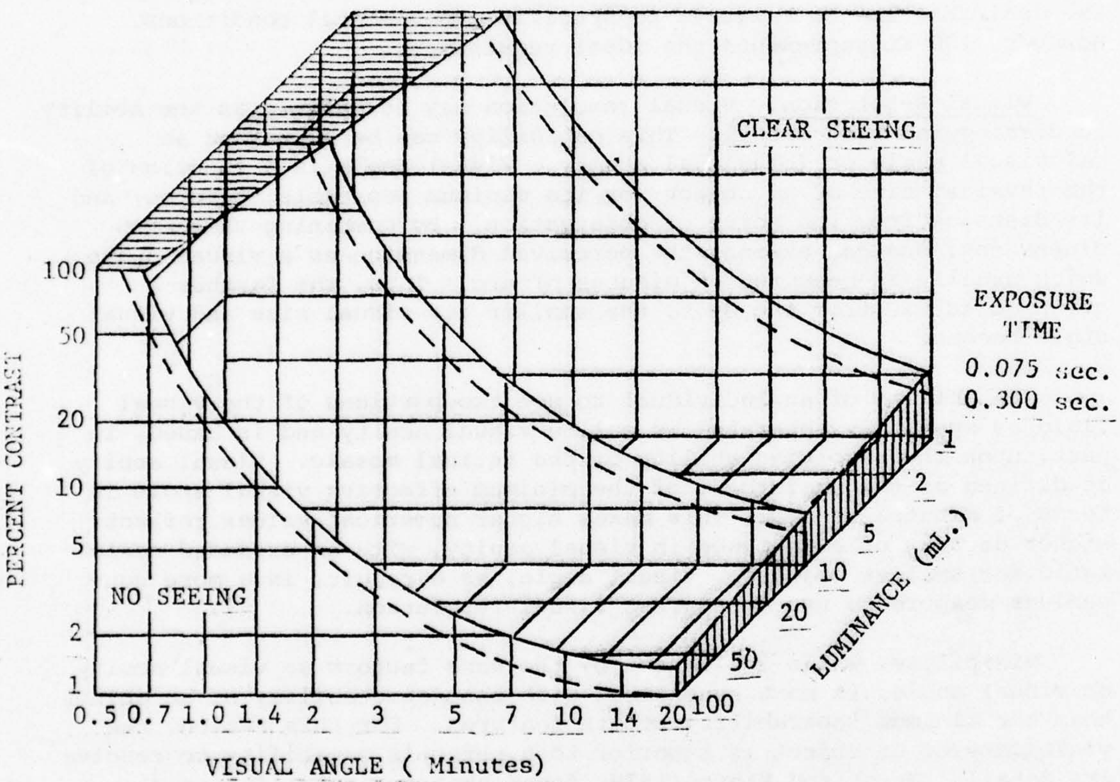


Figure 13. Background luminance and contrast required for bars subtending various visual angles under daylight conditions (from Wulfeck, 1958).

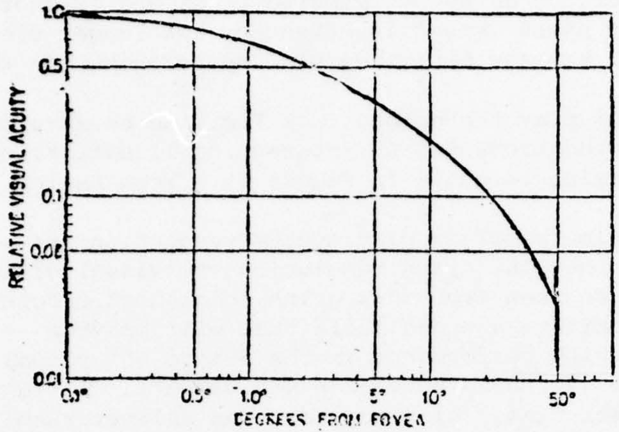


Figure 14. Variation of visual acuity relative to degrees from fovea (from Smith, 1966).

Under dynamic viewing conditions, visual resolution or the visual angle at which targets can be detected, recognized, and identified is appreciably less. According to Bailey (1974),

> A rough guideline for target acquisition capabilities of the human eye is as follows: target detection--when target subtends an angle of 2 to 5 arc minutes; target recognition--at an angle subtended of 4 to 10 arc minutes, and target identification--at an angle subtended of 8 to 16 arc minutes.

These values are influenced by many variables, in addition to visual capabilities (e.g., search time).

One way to establish a visual resolution requirement is to determine the minimum discriminable feature that one would like to see. For day NOE flight, objects as small as 6 inches in diameter at a 500-ft viewing range would appear to be an acceptable criterion, with a 12-inch diameter at 1,000 ft (i.e., tree limbs and branches). As discussed earlier, an analysis of motion films has indicated that pilots view objects between 500 and 1,000 ft. In Table 5, it can be seen that a 3 arc min display would be necessary to view a 6-inch and a 12-inch diameter object at 500 and 1,000 ft, respectively. 3 arc min is also compatible with target detection data. For example, 3 arc min is needed to detect a target with 20% contrast (Fowler, 1972). As a result, 3 arc min can be established as a reasonable resolution requirement for day NOE visual studies. The impact of angular velocities on this value is

negligible. As shown in Table 4, the highest angular rate is 207° sec at 45° from center, at an 800 ft viewing range and 40 knots airspeed. The impact of higher speed is offset by the longer viewing ranges. In addition, the eye minimizes blur by tracking the target.

Current visual display technology is a limiting constraint in meeting the above visual requirement. An interesting illustration of the degree of this constraint is shown in Figure 15. From Bailey (1974):

> The author's estimates of display system resolution are superimposed on the plot graph resolution vs. visual efficiency. It can be seen from this graph, that high resolution color TV monitors are available that will provide visual displays with performance in the 50% to 60% visual efficiency range (20/60-20/80 vision equivalent). A high resolution, direct view, color monitor, can deliver resolution in the 2 to 4 arc minute range for a 60 degree field of view display. This resolution will be degraded if the video signal originates from an "optical probe, terrain board, and TV camera link," or if collimating optics are used to provide an infinity display.

Depth and Visual Perspective. The illusion of depth will also be important to assure scene perspective and visual orientation in searching a target area. The pilot also relies on depth perception to assess his altitude above the ground and trees. Some visual theorists (e.g., Gibson, 1950) argue that the predominant factor in depth perception is the receding textural gradient of the viewed scene. This is seen as the explanatory basis for visual phenomena such as size constancy due to the fixed ratio of magnitudes of the stimulus gradients. According to Gibson, the important visual determinants of depth perception are

- Receding textural gradient,
- Linear perspective,
- Aerial perspective (haze),
- Motion parallax, and
- Realistic horizon or vanishing point.

The implication of these considerations is that, to the extent feasible, a true analog and distortionless representation of the real world is needed in both the stimulus source (e.g., terrain model) and visual display (e.g., virtual image). Another associated consideration will be the maintenance of scene perspective during pilot head movements. An important feature of a virtual-image display, in this respect, is that it permits the impression of motion parallax (i.e., the apparent motion of objects relative to each other as the observer moves his head).

Contrast. At the higher illumination ranges, contrast sensitivity increases with visual angle. As Figure 14 shows, a 5 arc min object can be seen at 2% contrast, a 3 arc min object at 3.5% contrast, and a 2 arc min object at 5% contrast. This will have implications for NOE

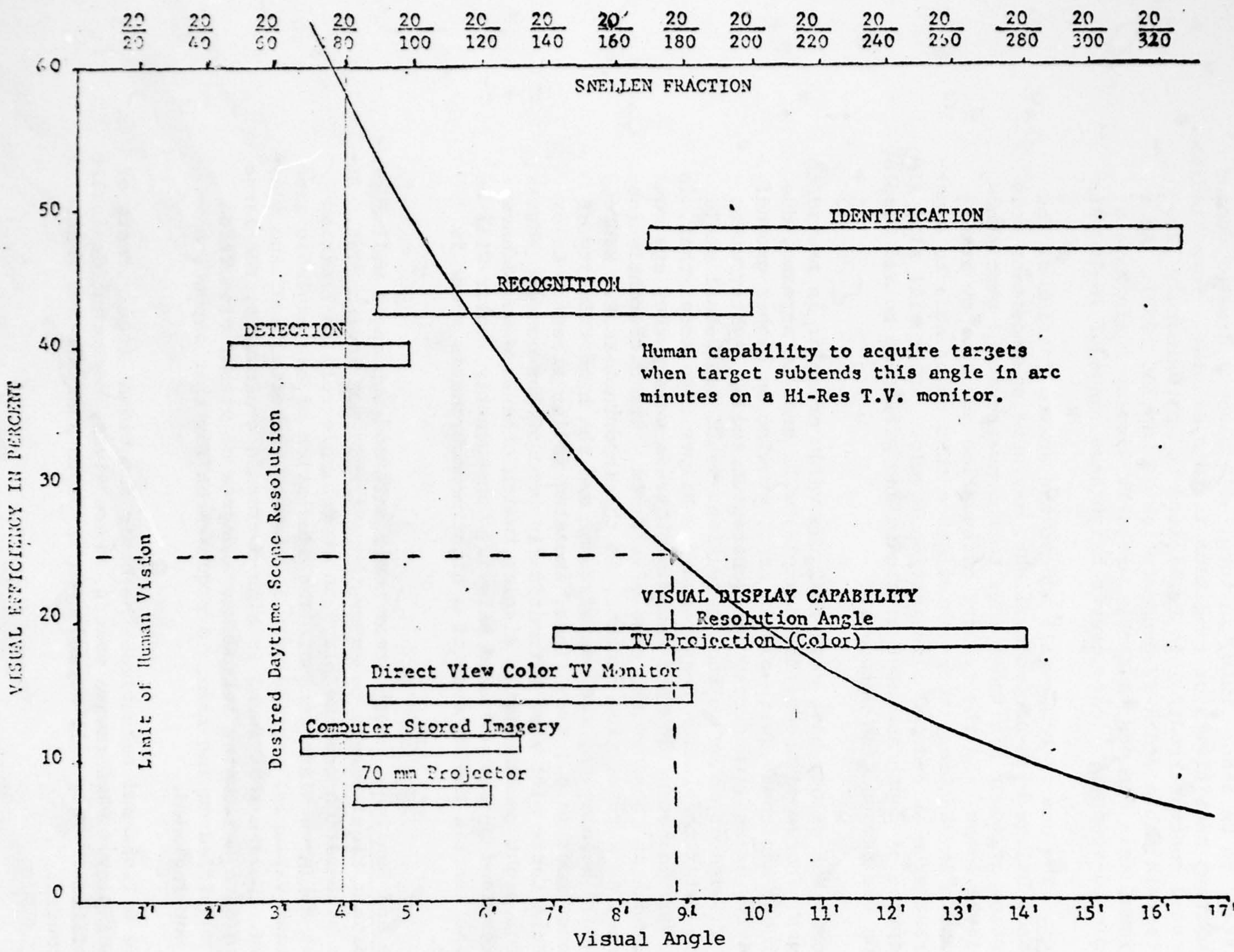


Figure 15. Visual resolution requirements and display capabilities (Bailey, 1974).

flight. Since viewed objects will generally be larger, they will need less contrast to be seen. This, in turn, will place a greater demand on low-contrast sensitivity or rendition in this display. Some studies have reported contrast control to be limited to approximately $\pm 2\%$, using a terrain table and a TV presentation (Ozkaptan, 1968). At a very minimum, this demands that the camera-TV display chain have a logarithmic 10-step gray scale over a brightness range of 10-100 FL.

Color. The use of color will add to the analog realism of the display and, unlike high-altitude flight, may have an important role in perception at lower altitudes, due to the nearness and prominence of the viewed scene, and the reduced attenuation of color by atmospheric haze. In addition, there is evidence that color adds to apparent contrast even at reduced illumination levels. Color will also aid the perception of depth at lower altitudes and will tend to aid display resolution for recognition purposes.

Several NOE pilots have described the value of color in providing visual cues. Hardwood trees, for example, will grow in streams, due to their deep tap roots, with pines, etc., growing on higher ground. Consequently, areas with streams are characterized by lighter green colors. The use of color in such situations would add detail while helping to relax resolution requirements. Pilots also noted that, in general, they do not notice the details of trees unless they are conspicuous, such as those at the edge of a field. The differentiation of one tree, as a tree, from another, is the important task. Hence, realism would be aided by the use of color and the high fidelity of conspicuous trees (e.g., tree lines, isolated taller trees). Color on a terrain table will also automatically produce the correct shades of gray for night monochromatic display, which otherwise would have to be determined by photometered values. Consequently, color will be used on the terrain table, even if a night monochromatic scene is simulated.

Haze and Sunlight. Both atmospheric haze and sun angle will represent important requirements to assure a realistic NOE environment. Atmospheric attenuation or haze plays an appreciable role in limiting visibility at large slant ranges. The simulation of sun angle is also an important variable, particularly in view of the effects of sun glare and shadow. Unlike that found in high-performance aircraft, the large windscreen of a helicopter introduces a degree of visual distortion which is magnified during rain. A requirement for this aspect, however, is not included.

Table 6 lists and summarizes the basic functional requirements of a visual display. Performance values, where given, represent desirable characteristics. They will depend upon in-depth analysis and feasibility studies.

Table 6

Summary of Display Visual Requirements

Characteristic	Period: Day	Night
FOV:	Horizontal 120° Vertical 30°-40°	Same
Resolution:	3 arc min	Same
Gray scale:	Min 10 shades of gray, logarithmic	Same
Luminance:	50-100 FL	10^{-1} to 10^{-5} FL
Chrominance:	Full color	Monochrome
Haze:	0 to 20 miles	0 to 1 mile
Glare simulation:	Sun glare	Lunar glare

Motion Requirements

Motion cues are secondary to the role of visual cues and are required only insofar as they assure the validity of the psychomotor responses to the visual cues. Such considerations as "realism" or transfer of training effectiveness, are not of central importance in this context. Moreover, motion requirements for the transfer of training may not be the same as those necessary for the validity of operator responses in a research facility.

During NOE flight, with a qualified pilot, motion forces are barely perceptible to a passenger. The pilot plans ahead and glides his aircraft between obstacles in a smooth and continuous manner. Abrupt or large excursions would be dangerous at the terrain clearances flown. The uncertain pilot is observed to be more hesitant and abrupt in his control motions, and he usually flies at a higher altitude.

Martin Marietta used an "Analyst Projector" to analyze movies taken at Fort Rucker to determine helicopter motion cues at NOE altitudes. Five-and 10-frame sections were taken, which represent approximately 2/10-sec and 4/10-sec durations, respectively (at 24 frames per sec). The angle change between two five-frame sections represents velocity (deg/sec). The difference between two such velocity components, when

divided by their time component, equals acceleration (or deg/sec^2). By means of this approach, it was determined that for the roll acceleration, "The pilot has a probability of .0884 of experiencing an angular acceleration of over 100 deg/sec^2, a probability of .2781 of experiencing over 50 deg/sec^2, and 0.4553 of experiencing over 25 deg/sec^2" (King, 1975). While highly tentative, scaling from an equivalent high-performance motion base (simulator), the equivalent pitch and yaw response would be 18 deg/sec^2 and 130 deg/sec^2, respectively. These accelerations are well above human threshold values, which are reported for angular accelerations to be between .035 deg/sec^2, and 8.2 deg/sec^2 with a median of about 1.0 deg/sec^2 (Clark, 1967).

The nature of the control procedures employed in a helicopter at NOE altitudes may lead to the high-acceleration components. This effect is due to the use of the collective control to initiate a maneuver, then the cyclic, compensated for by kicking the antitorque pedals. Pilots have reported that the motion cues between lower and higher speeds (e.g., 40 and 100 knots) were essentially the same, because they fly at higher altitudes with increasing speed, eliminating the abrupt motions needed to avoid obstacles. Heave has been reported by some pilots to be an important motion cue. During hover, pitch and forward translation and roll and lateral translation appear to be the important motion dimensions.

A general review of the literature indicates that simulated motion cues in research studies help a subject to perform his tasks more precisely and with less time lag. In one display tracking study, it was reported "...that the motion variable is a reliable contributor to the overall experimental variance" (Robert, 1973). This is probably true because the body senses acceleration before the eye by approximately a factor of four, and as a result permits the initiation of earlier and hence, more precise, control movements (Puig, 1970). Since proprioceptive cues are sensed earlier than visual cues, the lack of motion cues can lead to a delay in a pilot's perception and response, with an overreaction when the cue is sensed visually. Motion cues are also reported as being important during a hovering maneuver. Of particular importance is the fact that motion enables a pilot to sense changes in an aircraft's attitude when he is attending to other tasks. One pilot also reported that in the absence of motion, his head would follow the visual scene rather than counter-rolling to reduce the inertia induced by the cockpit motion. The critical consideration, however, is the fact that motion cues, when in phase with visual stimuli, lead to more precise control movements.

The important question, therefore, is not whether motion is needed, but how much motion is needed. The following observations can be made in this respect.

1. Proprioceptively, a subject is more sensitive to onset cues, less to acceleration cues and least to velocity cues (Puig, 1970).

2. Sophisticated motion bases, at best, give onset cues and limited acceleration cues. The latter are made possible by physiological adaptation to sustained acceleration. These systems also have to rely on mechanical repositioning or washout, below proprioceptive thresholds, in order to return to original conditions.

3. The filtering of motion base commands results in limited simulation fidelity, except for onset cues. This is justified by the hypothesis that onset cues are more important than steady-state acceleration cues (Bailey, 1974).

4. The larger motion systems are not sufficiently fast to precisely provide the low amplitude and high frequency motions. G-seats apparently, as described later, provide a more rapid onset cue.

5. It has been reported that subjects are unaware when motion cues for roll have been randomly reversed in a simulator, which implies that the alerting cues rather than the direction cues are dominant (Roscoe, 1974).

6. The sensation of motion is, in part, mediated by the pilot's seat, whether the motion is initiated internally or externally to the seat. In the former case, however, the cockpit frame would not move.

7. Large motion cues are sometimes in error and may outweigh the potential value of good cues or do more harm than no motion cues (Bailey, 1974). The error, in many motion systems, becomes apparent when visual display systems are added at a later stage.

8. Reports are inconsistent regarding the value of large motion systems. The type and quality of the motion bases, the degree of simulation, and the task demands reported have been highly variable, thus limiting generalization.

The above information implies that a large motion system is not a prerequisite for valid simulation purposes, particularly in view of the inadvertent anomalies that can be introduced without obvious, detrimental results. The simulation of alerting or onset cues may be sufficient.

An analysis was conducted by ARI and Martin Marietta with a wide FOV (120°) 70mm film (square frame) created by the IMAX Corporation of Canada. The film had scenes with significant visual motion cues such as roller coasters and low-flying stunt aircraft. It was determined that when the FOV is large (with no other apparent frame of reference) and the visual scenes are lifelike in size, the illusion of motion is induced in the observer. The illusion is sufficiently strong that the

viewing room appears to move rather than the screen. A similar illusion was created with an NOE film, when viewed close up.

The same phenomenon has been reported in the Differential Maneuvering Simulator, located at NASA, Langley Field, Va., which has a large FOV with a very prominent moving horizon (Ashworth, 1973). The pilots become so intent on the visual task that a G-suit alone appears to satisfactorily reinforce the visual cues. It appears, however, that the pilots need at least one familiarization flight before this illusion of motion becomes complete. In this instance, the G-suit is not intended to be an analog of any motion dimension. The implication, once again, is that a large-scale motion system may not be needed with a large FOV windscreen display, and that a cueing device, such as a G-seat, may be sufficient.

As a result of the above observations, researchers visited Singer Simulation Products Division, accompanied by Army helicopter pilots, to review and discuss the G-seat installed in the AF Simulator for Air to Air Combat (SAAC), which also has a 6 DOF synergistic motion base (i.e., hydraulic activators are differentially driven to generate commanded cockpit motions). The following verbal information was obtained. The G-seat consists of a seat pan, back pan, and thigh panels. The seat and back pan have the following modes of operation:

1. Contouring--the units exert pressure, "shape" themselves about the thighs and back of the pilot.

2. Translational--the unit shifts longitudinally and vertically.

3. Attitude--the unit tilts angularly like a rocking chair.

The thigh panels (3 units) also have three modes:

1. Vertical--the outer edges pitch up.

2. Lateral--the panels make a coordinated tilt to the left or right.

3. Splay--the three panels differentially tilt in the longitudinal plane to create an inclined plane.

These units are all stimulated by the simulated 6 degrees of motion of the SAAC simulator. A dynamically activated seat belt and G-suit are also used. These units, however, are primarily correlated with acceleration and G-loads.

The SAAC flight cabin is located on the top of a spider-like, 6 DOF hydraulically operated synergistic motion base. Two similar systems are used to simulate air-to-air combat between two high-performance aircraft. The systems, therefore, are used primarily for high-amplitude and low-frequency type maneuvers. Characteristic helicopter motions at NOE altitudes, on the other hand, can be described

as low amplitude and high frequency, which is similar to an air-to-air tracking task before weapons release. This latter type of maneuver was also flown in the simulator. The evaluation of the G-seat consisted of both tracking maneuvers and high-G aerial dynamics (e.g., loops, barrel rolls). During these tests, the G-seat and the 6 DOF motion base were used separately and together. Two pilots served as the subjects, with a third pilot for selected tests. Because of its developmental nature, the gain of the G-seat was set at three levels to determine the optimum setting. The dependent measure employed was accuracy of aircraft control. Although the data analysis was not complete, the following results and impressions were reported by Singer personnel.

The pilots stated that the G-seat felt natural. For tracking type maneuvers, the G-seat alone was considered superior to a nonmotion situation, a little smoother than the 6 DOF system alone (programing errors may have been involved), and about the same for the G-seat and 6 DOF systems used together. In the higher G environments, the value of the G-seat appeared to be only complementary. Of the 6 DOF simulated by the G-seat, it was reported that all cues were excellent except for roll and lateral motions. It was noted, however, that these motions could be improved if programed for the helicopter environment. It was also stated that the G-seat appears to provide effective and more rapid onset cues, although originally designed for sustained acceleration cues in a high-performance aircraft environment. The final report of these tests should provide more definitive information.

An operating G-seat was not available. Trial flights by the author in other Singer products with 6 DOF synergistic systems and visual displays indicated that the motion cues themselves are barely perceptible in relation to the motion dynamics of the visual display, and are a part of the background which appears to be responded to subconsciously. The motion cues appear to enhance the visual scene and are more noticeable to experienced pilots, who neither look for nor concentrate on the cues themselves. The author, for example, could barely sense the difference when the motion system was on or off, whereas for the helicopter pilots, it represented a more complete environment and experience.

Dr. Stark, of Singer, expressed the potential value of a G-seat effectively, as follows:

> So far, as I indicated in our phone conversation, we have very little data on the contribution of the "G" seat to simulator utility, but our limited experience is encouraging. It appears that, while the seat was intended to provide cues to sustained acceleration, it also provided excellent motion onset cues. These, in turn, appear to be effective in the initiation and support of control inputs, which we usually consider to be visually oriented. This was observed in SAAC, in an airborne target tracking exercise. Addition of the seat roll mode to the normal cockpit motion improved tracking performance

and made it more representative of what the pilots recalled in F-4 ACM. It seems to me that Nap-of-the-Earth flying is similar to target tracking, in requiring rapid, accurate, and relatively small flight control inputs. "G" seat feedback may be effective in this, as well as in target tracking, by providing the immediate directional and velocity cues, which the visual sense would otherwise have to integrate before a control input could be generated. Although the "G" seat may be useful in NOE simulation, it would seem that two or three degrees of cockpit motion might be important in supporting the control of gross changes in flight path angle. You may also find that this depends to some extent on the type of visual scene you have available.[8]

In addition to the SAAC simulator, the G-seat has been installed in the Advanced Simulation Undergraduate Pilot training research simulator (ASUPT) in the Human Resources Laboratory at Williams AFB. It was reported that while formal tests are being planned, personnel at the Human Resources Laboratory had been very favorably impressed by the G-seat during their informal evaluations.[9] It was noted that, subjectively, the G-seat alone had been more effective than the motion system alone, due possibly to the difficulty in integrating the larger 6 DOF motion system with the visual display. It was also reported that the G-seat was used in a full range of aerobatics, and that while it could not replicate the extreme motions associated with some of these maneuvers, it appeared sufficient to cue the pilots to excessive G-forces, thus enabling them to retain control of the aircraft. The pilots, otherwise, would exceed the structural limitations of the aircraft in some of the more dynamic maneuvers. It was also felt that for some of the low-amplitude, high-frequency maneuvers, the G-seat was faster than the regular motion base, and provided important alerting cues. It should be noted here that the G-seat operates primarily through the haptic or skin senses, whereas the larger motion systems operate primarily through the vestibular senses (although seat-of-the-pants cues are not lost).

From the foregoing, it may be assumed that a G-seat alone may be adequate for most of the flight perturbations during simulated NOE flight, particularly if flown over moderately contoured terrain, such as at Fort Rucker or in Central Europe. The results of the formal tests that are planned and being conducted with the SAAC and ASUPT simulators will help to provide a definitive answer. It appears to represent a reasonable risk, however, particularly if provisions are

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[8] Personal communication. Dr. E. Stark, Singer Simulation Products Division, October 1974.

[9] Personal communication. D. J. Smith, Human Resources Lab, Williams Air Force Base, December 1974.

made for the addition of a conventional motion base at a later time if found to be necessary. With a G-seat, the subject will be cued to the onset of acceleration through his haptic senses, which will be continued visually by the display.

Mention should be made here about the recurrent assertions that a motion system is needed to prevent the occurrence of vertigo or nausea, even though a motion system does not guarantee the absence of this phenomenon. There is some evidence that simulator sickness can be attributed to the lack of fidelity in the motion and/or visual cues, rather than the presence or absence of motion cues alone (Miller, 1958).

Terrain Table

A terrain table appears to offer the greatest flexibility and control of experimental conditions. It provides a true visual analog of the real world, including the important cues for depth perception. The characteristics of such a terrain table, however, are important to assure a meaningful research context in terms of type of topography, flight time, model size and scale factor, and adequate model detail for flight realism.

Type of Terrain. A helicopter at NOE can be masked by any object such as houses or large hills. Trees, however, represent one of the most common terrain features for masking, as well as one of the most difficult to fly among. Trees are an important dimension, but the nature of the terrain characteristics, such as open fields, hilly areas, etc., will also be operationally relevant. The masking, luminance, and thermal characteristics of a background will also vary widely with differences in topography. For this reason, the following types of terrain should be considered.

- Open fields with sparse farm-like buildings and scattered trees;
- Densely treed and moderately contoured terrain with stream beds (e.g., Fort Rucker);
- Highly varied terrain--mountainous, hilly, and rugged, with forested ridges, and rolling valley floors with varied tree density (e.g., Hunter Liggett Military Reservation);
- Desertlike areas; and
- Seasonal variation for the above topographical features.

A wide range of representative terrain characteristics would be desirable. The limited size of the terrain table, however, as well as the need for relatively uniform flight conditions, within the available flight time, limits the topography to one basic choice.

The wooded and hilly area north of Fort Rucker appears to be the appropriate type of terrain since it poses the greatest challenge for NOE flight. An appropriate representation of central Europe that resembles the Fort Rucker area will also be included. Mountains and other unique terrain features, if used, would be too quickly learned. Fort Rucker is relatively uniform in elevation, but slight changes are noticeable at NOE altitudes; in this respect, it will be important to simulate valleys, draws, and depressions. Man-made objects characteristic of the areas simulated will also be included for greater realism (houses, roads, telephone poles, etc.)

Scale Factor. It was noted earlier that, in NOE flight, it is not unusual for the cab of the helicopter (or the pilot's line of sight) to be below treetop level, with the rotors skimming the top of the adjacent trees. In valleys, draws, and similar depressions, the helicopter will also be below the level of the surrounding terrain. An important limitation in NOE simulation, as a result, is the physical interaction of the probe with the model, and the minimum simulated altitude made possible by the minimum allowable height of the probe above the model. For example, the latest probes maintain their optimum resolution capabilities to within .2 inch from the surface of the stimulus source. Thus, on a 600:1 scale model, studies can be effectively conducted to within 10 ft of the top of the model. Effective resolution, however, when the probe is in and among the "trees" (particularly in the vertical plane), provides the most difficult optical challenge. As the model object size increases (or scale ratio decreases), lower simulated flight altitudes become possible with increased resolution and depth of field. This occurs, however, at a reduction in the amount of ground area that can be searched. A scale factor somewhere between 300:1 and 600:1 is necessary to permit a satisfactory trade-off between these conflicting considerations.

A 4- x 6-ft terrain table was developed for ARI by the Army Defense Mapping Agency Topographical Center to permit investigation of various scale factors, as well as tree simulation techniques. Tree sizes were varied on the table to represent 600:1, 300:1, and 225:1 scale factors.

The above scale factors were viewed with an optical probe of a given focal length and lens aperture. Acceptable resolution and depth of field were discernible at each of the three scale factors. It was also noted that perceptual resolution exceeded what one would normally expect from stated optical resolution values. The reason was believed to be that optical resolution was based on stringent criterion, such as the separation of two points of light or alternating bars, rather than the recognition of whole shapes or figures, which is a simpler and more relevant perceptual process. A question also arose regarding the optimum tilt plane, focus, focal length, and aperture of a probe at NOE altitudes and the associated resolution and depth of field of these alternatives, including an assessment of their perceptual adequacy under both static and dynamic conditions. A study was performed by

Martin Marietta, with an early model "Scheimpflug" probe in order to investigate these factors. The results are reported in King (1975).

Level of Detail. As noted above, the 4- x 6-ft table was used to investigate various scale factors and simulated tree techniques as they affect level of detail. Four types of trees were constructed, relative to the scale factors mentioned above:

1. Wire trees--Built by twisting narrow-gage wire into tree trunks, with individual wires serving as branches or tree limbs. These were left natural to represent winter conditions or were sprayed with crushed foam to represent other seasonal variations.

2. Lichens--Various lichens which exist in nature were used to represent miniature trees, including tree trunks and branches.

3. Foam--Sponge foam rubber was shaped into trees.

4. Chemical tree milling--Developed by Martin Marietta Corp., Orlando, Fla. Photographic negatives of trees were used to chemically mill various metallic substances. Each piece is folded at a 90° angle, and two such units are glued together along their folded edge to form a three-dimensional tree. Scale or size is readily changed by variation in the amount of enlargement used. Since photographic negatives are used, there is almost one-to-one correspondence to the actual object. Light amounts of powdered foam can be sprayed on the trees for additional realism (leaves) or seasonal variation.

Other techniques exist, such as plastic sheets with conical protrusions sprayed with short, hairlike particles. The impression of a forest is created without the need to make trees individually.

Seasonal variations were included in the above techniques, since they influence NOE performance. Heavy foliage in the summer increases the visual contrast between trees and other objects. While this aids the pilot's ability to discriminate objects for lower level flight, he loses detail for navigation purposes. Conversely, in the winter, it becomes easier to navigate and harder to fly NOE.

The above techniques were viewed through an optical probe to assess their degree of realism under magnification. The wire trees, with and without foam, appeared to be the most realistic. The chemically milled trees were not as impressive, apparently because they were pinned together poorly.

When motion films of NOE flight are viewed, it is apparent that most trees present a uniform mass in appearance, with the taller trees appearing as individual trees or as trees along ridge lines. Hence, a combination of techniques can be used to create both dense flyover

areas and areas where the simulated helicopter can fly with the cabin or rotor between the trees. The wire trees may be most suitable for the individual tree simulations, with techniques such as the hair-covered plastic extrusions being suitable for the dense flyover areas. Winter and summer combinations will also be replicated, although this feature is less important for simulated night conditions. Spring and fall conditions primarily represent color variations, which will not be useful for the monochromatic night simulation that is planned.

Model Size. A large amount of ground area is important to assure adequate flight time for research purposes. As noted earlier, average NOE flight time in the ARI field experiments is 20 to 40 minutes over a course 26 to 32 kilometers (km) long. For simulated flight, it was decided that a course as short as 20 km would represent a meaningful NOE problem, which at 40 knots speed would equal 15 minutes of flight time, with more or less time becoming available as flight speed varied around the 40-knot basic speed. Thus a simulated terrain table of about 7 km by 7 km would be needed to permit a variable course of approximately 20 km. At a 600:1 scale factor, the required terrain table size would be 40 ft by 40 ft.

Various alternatives were investigated to extend this flight time for purposes of greater mission realism and pilot fatigue. Such secondary stimulus inputs as transparencies were considered and found to be too costly or infeasible at the present time. The feasibility of using instrument flight reference (IFR) was also considered to achieve this objective. An established NOE tactic includes a precision IFR approach to an IP at high altitude, with a circling approach to reach NOE altitude near the FEBA. This method can be used to extend flight time.

Other considerations with respect to terrain models include the characteristics of the paint used, the surface texture, and the reflective and radiometric qualities of the model relative to the range of wavelength studies desired.

Sensors and Visual Aids

Sensors. FLIR and LLLTV represent the most frequently used sensors for low-level night operations. Several field tests have been conducted or are underway with these sensors. Extensive tests, for example, have been conducted by the Night Vision Laboratory (Stich, 1973). The Combat Developments Experimentation Command at Fort Ord, Calif., is currently conducting tests with a specially instrumented cobra helicopter. The aircraft is designated as OPTIC (OTAS-PNVS Tactically Integrated Cobra). OTAS and PNVS represent its two primary display systems. OTAS is primarily a target acquisition system, consisting principally of a FLIR, daylight TV, and a 10-inch CRT, which will be located in the front seat. The PNVS has a 10-inch CRT. It is designed primarily as a navigation aid for the pilot for use

with a helmet-mounted display. Its principal sensor is IR. The pilot is able to view the terrain during conditions of daytime, total darkness, and limited visibility. Several variations of these sensor systems exist throughout the service (e.g., night observation goggles). Radar at this time does not appear to be a viable sensor for night work, in view of the demonstrated capabilities of FLIR and LLLTV. Simulation of these latter sensor systems with variable FOV and display characteristics is warranted. This type of capability will permit wider latitude in the control and manipulation of key variables in the investigation of new display concepts and optimum display parameters.

Electronic processing techniques to simulate the characteristics of various sensors will be useful in conjunction with a standard sensor, with characteristics varied to match the displayed scene of the simulated sensor. Computer capabilities can be used to select preset parameter levels and lend predictive and exploratory capabilities to a laboratory.

Visual Aids. The following visual aids will also represent important capabilities for night visual research.

- Helmet-mounted displays,
- Head-up display,
- Night-vision goggles, and
- Helmet-mounted sight.

Helmet-mounted displays (compatible with FLIR and LLLTV) permit a pilot to retain a natural view of the external world while seeing with one eye the sensor or augmented information to be correlated with what is seen directly. The head-up display consists of a combining glass which provides the pilot a collimated image superimposed on the real-world image. It represents a see-through display which will permit a pilot, depending upon the information provided, to maintain a heads-up attitude as well as constant orientation to the viewed scene. Aircraft attitude, status, and navigation information can be provided. The displayed scenes in the VFRF must be comparable to the real world as "imaged" by the system. Simulated, or actual sensor systems when possible, are implied.

Night-vision goggles are image intensifiers which can be used directly with the virtual-image displays proposed for the VFRF. They require stimulation by the collimated imagery at approximately the correct illumination levels. A helmet-mounted sight is a device to automatically slave the E-O sensor to where the pilot is looking, unless a manual control stick is used.

As noted earlier, other sensor systems must also be considered, such as potential stereoscopic aids and wire avoidance techniques. The former would be important because of the critical role of depth perception at lower altitudes. The ability to superimpose information on a virtual-image display from several image-generation sources

will provide flexibility for accommodation of other aids and devices. Provision must also be made for the latest navigation aids, which might include electronic map displays (raster scan on a CRT) and projected map displays from film transparencies.

In summary, an LLLTV and a FLIR sensor capability, with a helmet-mounted sight, should be built in. Provisions should be made in terms of space, power, and signal inputs for helmet-mounted displays, head-up displays, and navigation aids. Selection of a specific system within these areas may be premature at this time. To the extent possible, provisions should also be made for the future accommodation of stereoscopic aids, wire avoidance techniques, and other sensor aids. Finally, the visual display should be compatible with the use of night vision goggles.

Displays

Monitor displays will be provided for the LLLTV and FLIR presentations as discussed previously; however, a wide range of display studies (primarily CRT), is being planned, including such considerations as display size, location content, and contrast rendition. Provisions should thus be made for various display sizes and signal inputs, including potential cockpit locations. It may be easier, for example, for the eye to flick up to a display and down to the windscreen, rather than the reverse procedure.

Cockpit Requirements

Perfect fidelity is not needed in either cockpit arrangement, instrument response, flight control, or aerodynamic fidelity, as long as operator responses are equivalent to those in the actual environment, and realistic cockpit configurations and task loading are maintained. These considerations are discussed more fully in the section on "Research Utility." A general helicopter system is desired, and the system characteristics of the UH-1H will be simulated to the extent necessary, as described below.

Cockpit Configuration. Research flexibility will be limited insofar as a hard-mounted and operationally realistic configuration is used. A cockpit arrangement is desired wherein displays, instruments, and control devices can be easily mounted and removed; therefore, a cockpitlike research module is desired, wherein the location of the windscreen would be geometrically correct but all features could be readily changed. Problems of face validity are not anticipated in view of the conventional location of the helicopter controls and instruments that still would be maintained.

In the establishment of a concept, an early consideration was whether to simulate a tandem or a side-by-side cockpit, since it would have a major impact on the size and type of windscreen display adopted. The side-by-side cockpit appears to offer some significant advantages.[10] These are

- Ease of normal and emergency communications (including hand signals),
- Work sharing,
- Sharing of displays,
- Less overall panel area and lower cost,
- Increased crew confidence through direct association, and
- Better forward vision.

The large frontal area of a side-by-side helicopter does not appear to affect its survivability under weapon fire. A tandem helicopter, in this respect, may offer a larger side area. The important consideration here appears to be total cabin volume. The above reasoning is supported by the fact that new helicopter procurements are side by side (e.g., HLH, UTAS, ASH). In addition, the results of research studies in a side-by-side aircraft would be transferable to a tandem aircraft. Hence, a windscreen display is desired which permits two-man viewing, including simultaneous perspective viewing (i.e., common FOV with equivalent perspective of the viewed scene).

<u>Instrumentation</u>. Two levels of detail appear to be appropriate. The first, and more complex, level involves the use of a limited number of basic instruments with sufficient fidelity to allow valid pilot responses. The displayed values would be correct and directly correlated with aircraft state variables as determined by pilot control behavior and system characteristics. This level of instrumentation would allow IFR as well as VFR. The second, and simpler, level of detail would involve still fewer instruments and would be useful only for VFR flight at NOE altitudes. The instruments involved in both alternatives are shown below. Those associated with the second alternative are marked with an asterisk.

- Radar altimeter,*
- Airspeed indicator,*
- Attitude indicator,
- Altimeter,
- Vertical speed indicator,
- Compass,*

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[10] Personal communication with S. Moreland, AVSCOM, 10 June 1974.

- Course indicator (RMI),*
- VOR (variable omnireceiver),
- Turn and slip indicator*,
- Torquemeter,
- Gas producer (NI tachometer),
- Dual tachometer,
- Exhaust gas temp, and
- Communications equipment (very high frequency and frequency modulations display).*

The remaining instruments would be photo mockups. For many control panels, simulation would be at the procedural level (i.e., setting dials and switches). The first of the above alternatives will be used to permit extended flights with IFR.

Flight Controls. Two levels of fidelity are appropriate for flight control. The first would involve the appropriate system responses and control forces associated with the following:

- Cyclic,
- Collective,
- Antitorque pedals, and
- Throttle (on collective).

This level will be used with experienced pilot subjects in the primary operator compartment.

The second level of fidelity would include a cyclic for proportional attitude control and longitudinal velocity (including changing of vehicle rates as in a stability augmentation system), a collective for direct altitude rate command, and pedals (if necessary) for heading control. These controls will be placed in the secondary operator compartment and will be used by nonpilots or when copilot functions are being tested. This mode may also be used to override the primary control system, if the pilot subject experiences difficulty. A similar system is desired in the flight monitor station for use by the experimenter, with replacement controls for the cyclic, collective, and pedals by simpler means, if practical.

Aerodynamics. Pilot control responses vary relative to the flight control and aerodynamic characteristics of the system. A general helicopter system capability is desired with enough specificity for research validity, including the capability to simulate basic helicopter maneuvers, such as takeoff to a hover, landing from a hover, etc. In this respect, a wide latitude exists in the degree of simulation complexity possible. The helicopter operational trainer (HOT), developed by Singer Simulation Products Division, is estimated to have 80% to 90% simulated aerodynamic accuracy. Singer personnel estimated that, to achieve 100% aerodynamic accuracy, as in 2B24, or a 10% to 15% increase, the cost

would increase by a factor of 100.[11] Accuracy limits for the VFRF will be determined by the level of accuracy desired in the performance values. These values are given in the system specification (King, 1975). In general, minimum computer complexity is desired, yet consistent with the above, in order to minimize system costs. A fixed-based helicopter simulator used at NASA (Ames) for simulated NOE flight is illustrative of this approach. (This system is discussed under Other Research Facilities.)

Environmental Requirements

Vibration and noise are a significant part of the helicopter environment. Some pilots have reported that, once airborne, the vibration level is reduced and becomes less noticeable because of adaptation. Cockpit vibration is of sufficient intensity, however, to be perceptible in the inflight motion films. It should be included for purposes of face validity, as well as for any detrimental effect it may have on performance.

Engine noise, also a significant part of the cockpit environment, should be introduced via the pilot's headphones as an inexpensive way of inducing cockpit realism. On the other hand, aircraft responses to wind, barometric pressure, rough air, icing, and magnetic variation are not considered critical to the goals of the VFRF.

Calibration and Control

Instrumentation techniques and procedures for calibration deserve special consideration. The fundamental value of a visual research facility is the repeatability of the visual or displayed scene in terms of illumination, resolution, and contrast levels. This will depend upon such factors as

- Light balancing throughout the area of the terrain model,
- Degree to which object surfaces can be made to reflect the desired light level in relation to their background,
- Control of and electronic stability of the sensor and its electronic chain,
- Stability of the ambient light about the display, and
- Accuracy and precision of the photometer used for calibration measurements.

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[11] Personal communication with John Bradish, Singer Simulation Products Division, December 1974.

The above is equally true for the simulation of night conditions, since the reduction of light levels will be achieved by adjustment of the television gain and special filters, rather than by the variation of light on the terrain table. The establishment and demonstration of these techniques and procedures to desired tolerance levels will determine the basic validity of the laboratory.

In addition to the visual display, the VFRF will contain many complex and expensive subsystems that must be monitored by both system calibration and safety of operation. These will include the terrain table, transport mechanism, gantry, crew compartment, etc. A control console is needed for the checkout and calibration of these systems to desired tolerances, including manual and automatic operation as appropriate and the necessary computer interface. These requirements are discussed in more detail under Test Station Requirements.

To assure a quality device, system reliability, maintainability, environmental conditions, quality assurance, and good design and construction practices, including workmanship, safety, and human engineering standards, should also be considered.

PERFORMANCE MEASURES[12]

Data Requirements

A research simulator is only as good as its capability to discriminate and measure performance. The effectiveness of any device in this respect is dependent upon the salience and comprehensiveness of the performance measures selected. Nevertheless, this area appears to receive cursory attention. Several reviews have been made of research facilities. One study reported that "One of the areas in which simulator facilities visited were most deficient was the area of pilot crew scoring," (Bailey, 1974). Another source has noted that "It has been necessary to limit either the scope of the experiments or the extent to which results could be validated in accordance with the available type of performance measurement capability" (Knoop, 1973). It is evident that the value of a research facility is dependent upon the scope and sensitivity [illegible] the performance data. Gross or incomplete measures will impose severe constraints. As described by Siegel (1974), an effective performance system should have the following characteristics:

- Provide measures which are fully defensible from both the relevance and the validity points of view,

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[12] The following in large part is indebted to information prepared by Dr. A. Siegel of the Applied Psychology Corp. (Siegel, 1974).

- Provide data of sufficient reliability to allow precise statements relative to the effects of the variation of the research variables on the parameters measured,

- Present summarized and detailed data within a short time interval after any experimental run,

- Make possible full standardization of measurements across various situations/experiments,

- Be fully flexible to accommodate all anticipated conditions of use of the VFRF,

- Allow for future expansion,

- Be fully compatible with data processing equipment to be used in post simulation data analysis,

- Allow derivation of a total performance effectiveness score, as well as definition of why performance is superior in one case as compared with another.

Because the VFRF is primarily a visual research facility, many types of dependent measures or performances are involved. Desirable types of measurement are given below. These are relevant for all mission flight phases: takeoff, landing, hover, special flight, pop-up, and minimum terrain clearance (NOE). The measurement sets are as follows.

Visual.

1. Eye movement--Pilot eye movements and fixations relative to the viewed scene, including viewing time and viewing frequency. This may require a vision grid of varying cell sizes relative to the criticality of the area viewed. The grid would be remote from the visual display and would be activated by the oculographic equipment used.

2. Visual thresholds--The visual angles relative to illumination and contrast determined by the slant ranges at which objects are perceived (or avoidance action initiated), the object size and the prevailing experimental conditions. The automatic calculation of these values would be desirable.

3. Visual fatigue--Visual fatigue as inferred by variation of the above parameters (and others) relative to normative baselines.

System Measures.

1. Aircraft attitude and status--pitch, roll, altitude, airspeed, rotor, and engine RPM.

2. Flight control--this variable will be determined primarily by the following control displacements: collective pitch control, cyclic control stick, rudder, and throttle.

3. Navigation--heading, position, and deviation from a nominal flight path in both X and Y.

Mission. The following variables related to mission accomplishment will be determined.

1. Probability of locating a landing zone (LZ), initial point (IP), or landmark;

2. Time for mission completion;

3. Probability of object detection and recognition; and

4. Probability of object avoidance.

The latter measure would be calculated relative to simulator (probe) strikes of terrain features, assuming each strike would require a mission abort.

Communication. Tape recorders will record pilot and copilot conversations, including air-to-ground communications. These will be content-analyzed relative to the type, frequency, and content of the communications.

Physiological. As noted earlier, the concentration required by NOE flight, and the attendant stress appreciably reduces pilot endurance. The potential influence of different flight conditions and visual aids on this factor will provide important data. The following measures are desired: heart rate, blood pressure (systolic and diastolic), skin resistance, breathing rate, and auditory evoked response. Study is required to determine which, if any, of these measures will have discriminatory power relative to the planned research flight times.

Spare Capacity. Task loading can sometimes be assessed by the residual work capacity that a person has remaining, as measured on a secondary task. Spare capacity, in this sense, will be measured through the pilot's ability to perform a collateral mental task while he performs his flight duties. The collateral mental problems will be presented on a small CRT which will allow, as a minimum, presentation of 8 lines of information and 20 alphanumeric characters. The problems will be of the multiple-choice type. Although many cockpit tasks can

serve this objective, the proposed approach will permit accurate quantification of results.

The following characteristics must be considered for each of the desired measurements, as appropriate. Specific values are shown in the specification for this system (King, 1975), as developed by the Applied Psychological Corporation (Siegel, 1974).

- Range of measurement--stipulation of the minimum and maximum limits of the variable to be measured, e.g., the range of airspeed measurement will be from 0 to 200 knots.
- Precision--the maximum error allowable for the sampled data. In general, all parameters should be sampled and the value recorded within a period of 100 msec of each sampling period limit. For airspeed, a precision of ± 4 knots may be appropriate.
- Data reduction--the specific calculation required for each measurement, e.g., the number of crossovers, displacement from, or integrated deviation from a nominal value.
- Nominal values or flight paths--idealized flight paths or values when flown in accordance with given scenarios, which also serve as crossover thresholds.
- Sampling rates--the time interval between two successive measurements of the same parameter. In general, the sampling period will range between .1 and 120 seconds and should be individually selectable prior to simulation.

Other ancillary considerations can include:

- Conditions of measurement--when and how special measurements must be made; e.g., automatic blood pressure recording during all flight phases.
- Data analysis--special data analysis needs associated with a given measure; e.g., mean response times across data reduction periods for spare capacity.
- Measurement equipment--special equipment, when ancillary to the device, such as microphones and tape recorders.

It should be noted that performance criteria other than nominal values for flight status, are not listed here. While performance criteria are critical for training situations, they have a secondary role in research where the criteria are normative from cumulative experience or comparative between techniques, systems, and procedures.

Data Presentation

Several types of data readout and call-up techniques are desirable. One of the latest technological advances has been the use of CRTs (with keyboards) to read out alphanumerically the variables and parameters that have been selected and to display performance levels in graphic form. An advanced version of this type of capability is contained in Device 2B24 (SFTS). Its primary CRT is divided into three display areas with the following functions (Singer, 1974):

(1) Map plot area. Ground radio facilities, required ground track, and actual ground track are displayed for cross-country and approach area training missions. A ground controlled approach (GCA) is also provided in this area, when it is required. Aircraft number, heading range, and glideslope and centerline deviations are provided in alphanumeric form.

(2) Problem status area. An alphanumeric tabular display provides data on the training mode being used, aircraft number, student name, training problem and difficulty level, trainee performance history, instructor alerts to out-of-tolerance performance, parameter freeze status, adaptive training score, environmental conditions, and the status of programmed malfunctions.

(3) Altitude/airspeed area. An area at the bottom of the graphic display is reserved for graphic airspeed and altitude plots. These plots are updated at 4-second intervals, for the last 14.2 minutes of the flight. Abbreviations for parameters which are out of tolerance appear adjacent to the airspeed graph, and adjacent to the ground track plotted in the map plot area. This alerts the instructor to the condition, and also indicates that the student has received an audio alert for that condition.

The presentation described above is shown in Figure 16. An aircraft centered map mode is shown. This mode places the geographical position of the aircraft, at the initiation of the problem, at the center of the display. Map details are then shown as they appear in relation to the aircraft. The instructor may also display, in the map plot area, an expanded version of the airspeed or altitude versus time graph. The ease with which parameter levels can be established and data readout by means of this system provides an important research capability.

A research facility, however, requires more flexibility, including hard-copy printouts for permanent records, as well as more comprehensive and specialized recording means. Basic data recording and display objectives for the VFRF can be stated as follows.

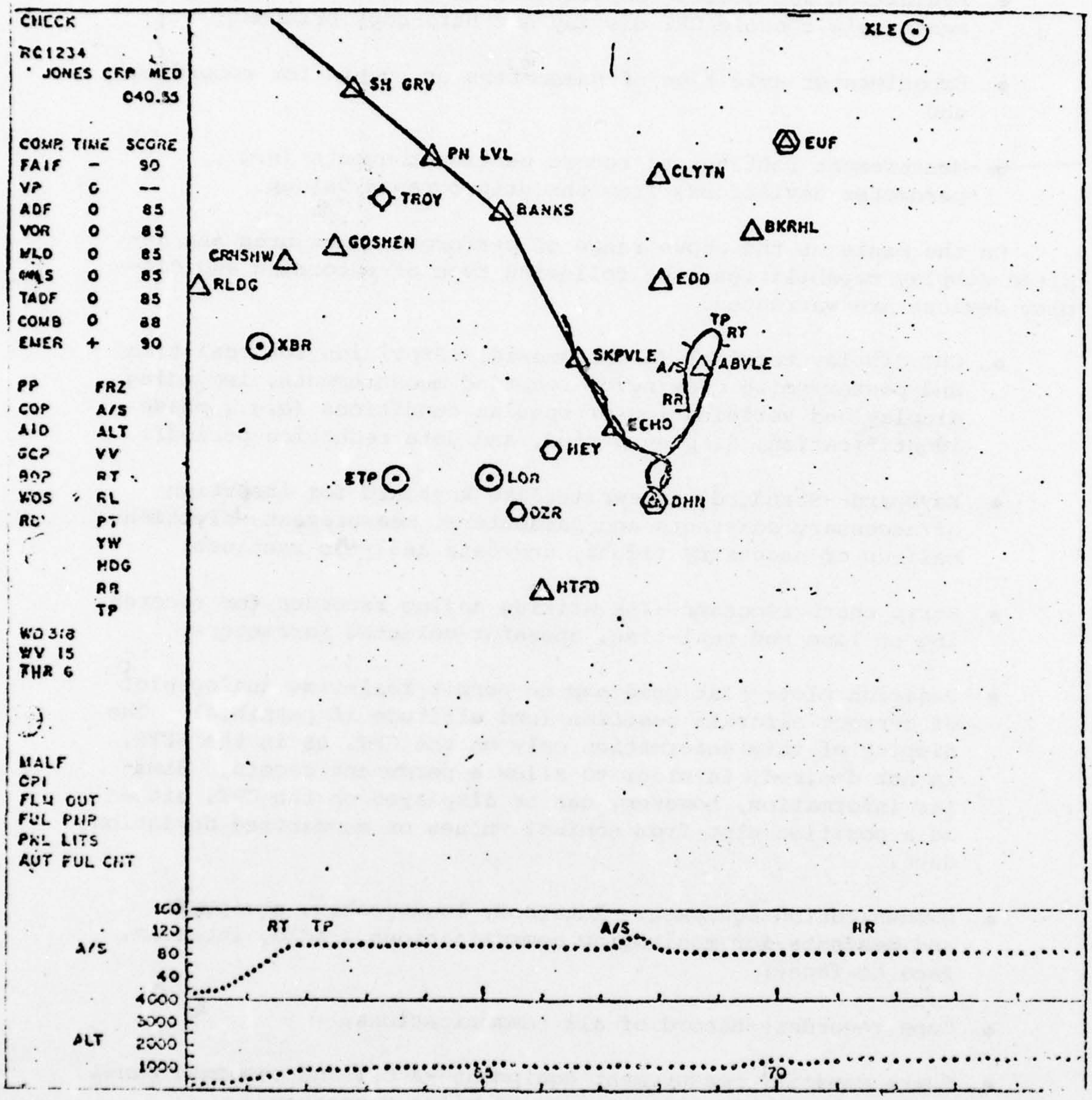


Figure 16. Aircraft centered map display (Hunot & Walsh, 1969).

- Storage of measures for real-time monitoring, postexercise printout, and end-of-course-program evaluation;

- Evaluation and scoring information available to the experimenter via console CRT display and hard-copy printout;

- Experimenter selection of parameters or events for recording; and

- Measurement routines to record pertinent events (e.g., parameter deviations) from the preprogramed values.

On the basis of the above range of performance measures and desired display capabilities, the following type of recording and display devices are warranted.

- CRT display terminal (alphanumeric)--Provision for real-time and postexercise viewing of recorded measurements, including display and verification of special conditions (e.g., phase identification, display period, and data reduction period).

- Keyboard--Standard, typewriterlike keyboard for insertion of necessary constants and parameters, measurement selection, call-up of necessary flight, and data analytic routines.

- Strip chart recorder--Ink writing analog recorder for recording on line and real-time, operator-selected parameters.

- Position plot--Flat grid map to permit real-time analog plot of current aircraft position (and altitude if possible). The display of this information only on the CRT, as in the SFTS, is not desired, in order to allow a permanent record. Similar information, however, can be displayed on the CRT, either as a position plot from nominal values or summarized deviation data.

- Communication equipment--Intercom, loudspeaker, equipment and headsets for monitoring communications (radio, intercom, face to face);

- Tape recorder--Record of all communications;

- Spare capacity measurement equipment--A CRT and response panel to present problems and to record pilot responses;

- CRT--Display of analog signals from any one of the biophysical measurements;

- Mission time and time of day clock--Capability to enter time "markers" in the recorded data; and

- Computer line printer--Printout of postsimulation data analyses.

The major components in the proposed subsystem and their functional interfaces and data flow are shown in Figure 17.

Data Processing

The data processing will consist of three basic steps:

1. Data reduction,
2. Data analyses, and
3. Data integration.

Data Reduction. This initial step will occur on-line throughout the simulation. The system will perform the data reduction specified for each parameter. Sampling, digitizing (when required), and data reduction will proceed automatically without real-time action by the experimenter, for all parameters and for all mission segments under computer control. The results will be recorded on magnetic tape for postsimulation analyses, or they can be displayed on the CRT if selected by the experimenter.

Data Analysis. This step will occur at the end of a simulation run and will have two steps.

1. Quick-look analyses. A special program will be prepared to present the following type of data within 30 minutes, on the CRT or computer line printer.

   a. number of phases, duration of each phase, and total duration for each phase,

   b. percentage of time crossover thresholds were exceeded for selected parameters,

   c. number of times the crossover threshold was crossed for each parameter,

   d. average and standard deviation of each biophysical parameter from nominal,

   e. the maximum out-of-tolerance value from nominal for heading pitch, roll, altitude, and airspeed,

   f. the percentage of correct spare capacity responses and average response time,

   g. RMS rotor and engine deviations,

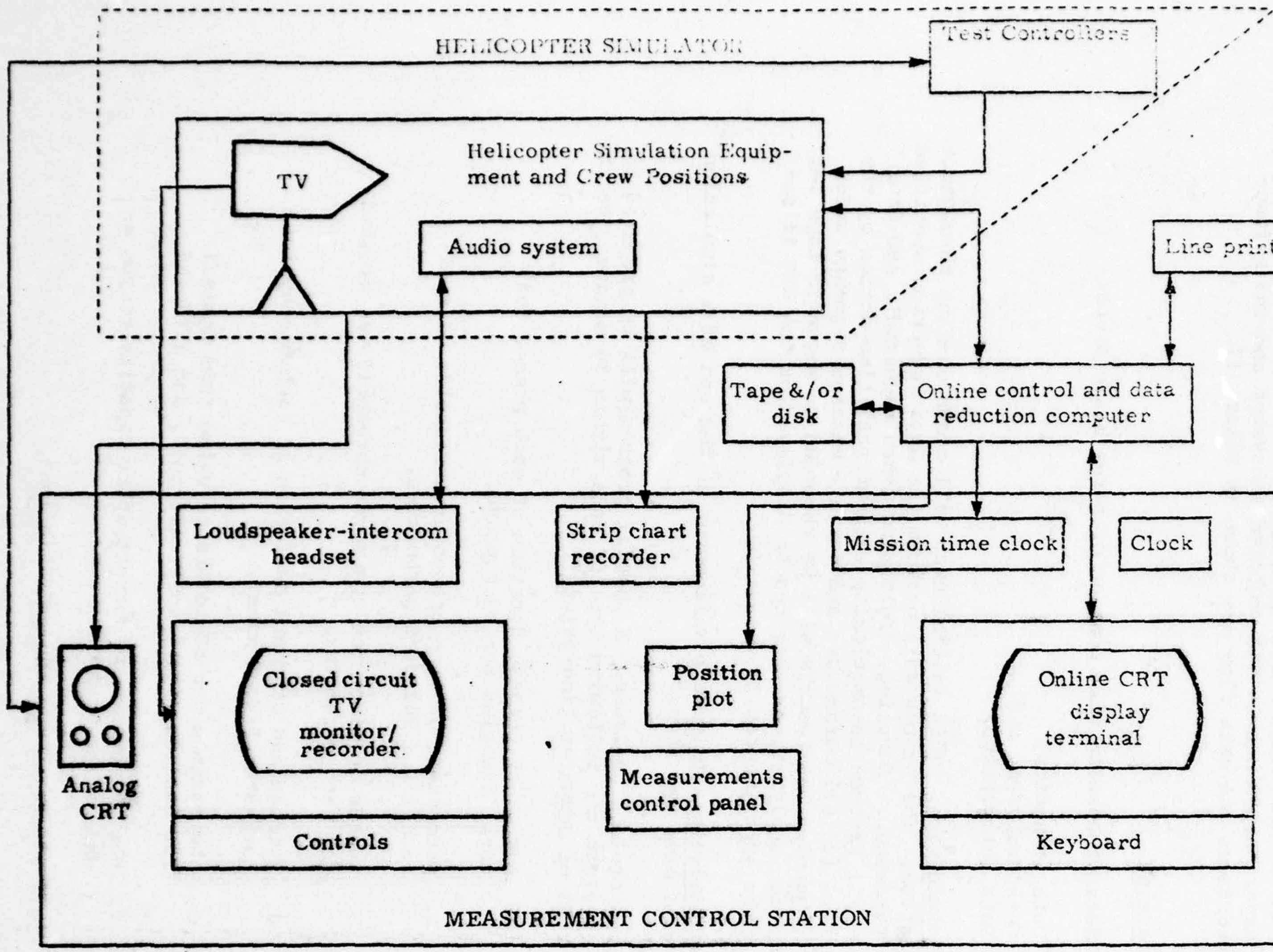


Figure 17. Measurement control station (functional flow) (from Siegel, 1974).

h. average count of each control movement per minute. (Siegel, 1974)

2. Basic analyses. General-purpose statistical programs will be supplied to process the data generated during the mission and in postsimulation analysis. These will include programs for such statistics as correlation and analyses of variance. Since the digital computer can record error deviations and all time and event happenings, various data can also be obtained. They can include printouts of the sequence of switch activations, out-of-tolerance errors, time and event printouts, total error printouts, as well as data summaries. Programing and controls must be provided to obtain the desired data on demand (Smode, 1972).

Data Integration. A composite or general system effectiveness measure has been proposed for this program by the Applied Psychological Services (Siegel, 1974). It consists of five score categories as shown in Table 7. The categories of flight quality and flight accuracy refer to the smoothness and precision of flight, respectively. Pilot effort exerted is related to pilot fatigue. The constituent components of these measures and the manner in which the general system effectiveness measure is calculated are listed in Appendix E. A simulation, by means of the process shown, can be compared against a nominal baseline, or any two runs (systems) can be compared against each other. An index of merit can also be calculated for each system, as well as a merit ratio between systems.

A collateral general systems effectiveness (GSE) measure is also proposed by the Applied Psychological Services, as a secondary evaluation of the total system. These measures are shown in Table 8.

These measures would be treated as individual qualifying factors, without recourse to a generalized effectiveness measure as above. The derivation of effective performance measure and measures of effectiveness will in themselves serve as research goals. Advanced research in the area of performance measurement has been increasing. In one study, up to 846 measures of performance were analytically derived for a captive helicopter-like device, the Jaycopter (Obermayer, 1973). From this set, multivariate procedures selected 398 preliminary components which could discriminate between instructor and trainee performance. A related approach involved a state transfer technique that has been developed under contract to the Air Force Human Resources Laboratory (Connelly, 1969) which is based on this rationale:

1. Demonstrated performances can at least be sorted according to the independent measure of performance.

2. Operator's actions which produce superior results can be modeled and examined to show how superior results are achieved.

Table 7

Score Categories Comprising General System Effectiveness

GSE score category number	GSE score category	Notes
1	Flight quality	Smoothness
2	Flight accuracy	Actual vs. nominal
3	Pilot effort exerted	Related to control movement
4	Pilot biophysical reaction	Related to mental stress
5	Accomplishment of mission objectives	Mission-oriented goals

From Siegel, 1974.

Table 8

Collateral Systems Effectiveness Data

Item no.	Item	Notes
1	Spare capacity a. Percentage correct responses b. Average response times	Measures capability to perform additional work
2	Eye movements a. Average time in each grid section b. Difference of two matrices	Measures extent of visual acuity
3	Communications (see Section 2.1, Siegel and Federman, 1973)	Team integration
4	Cortical evoked response a. Mean sigma and quartile deviation for amplitude and latency of cortical response	Experimental measure

From Siegel, 1974.

Transition matrix analyses are used for both performance discrimination and the identification of the effects of secondary tasks and time stress. Both continuous and discrete variables are treated by means of Boolean functions. The method appears to offer a valuable adjunct to standard statistical processing techniques.

Research on automated scoring has also been conducted by NASA at Langley Research Center to support the differential maneuvering simulator for air-to-air combat (Beasley, 1969). The utility of techniques such as these will be evaluated for application to the research program.

TEST STATION REQUIREMENTS

The test station will serve as the primary control and calibration station for the VFRF and will be the point of interface for all major subsystems (e.g., computer, crew stations, electronic subsystems). It will provide for the checkout, calibration, operation, monitoring, and data reduction for the VFRF experiments. The following design goals are desired for this station.

1. Flexibility of Usage and Design Modification--Maximum utilization of the reprogramable qualities of a digital computer is desired. With an appropriate selection of input-output devices, the introduction of new requirements should be possible by means of software changes alone. This type of capability will affect the flexibility as well as economy of design. Major reliance should be placed on computer keyboards. Where preprogramed tapes are also used, modifications should be possible via the keyboard.

2. Modularity--Modularity of design is important to assure the accommodation of a wide variety of special devices and tests, as well as to assure the flexibility and potential growth of the VFRF for the range of tests planned.

3. Two-Man Operation--Operation of the test station by no more than two men is desired, to facilitate the staffing and to minimize the cost of operation. This consideration becomes especially important if the VFRF is used more than one shift per day.

The test station will have three principal components to meet the above objectives.

a. Measurement control station--This station will initiate and control all parameters associated with the execution of an experiment.

b. System control station--This station will assure system operability, calibration and safety, including initial checkout and fault monitoring.

c. Flight station monitor--This station will have a dual function. It will permit monitoring of the windscreen display and selected cockpit instruments. It will also provide a backup capability to pilot and copilot functions when either crewmember is missing or not required in an experiment. In this latter mode of operation, it will be operated by the experimenter if his work load permits.

The functional requirements of these stations are presented below.

a. <u>Measurement Control Station</u>. The requirements of this station and those of the performance measurement subsystem, described in the preceding section, are almost identical. The major functions of an experimenter, in addition to the initiation and control of an experiment,

are the monitoring and evaluation of a subject's performance. The overall functions of an experimenter may briefly be summarized as follows.

- Determine experimental scenario.
- Program or select preprogramed scenario via keyboard and/or tape.
- Determine desired parameter levels and error tolerances.
- Enter desired parameter and error tolerances.
- Establish and enter desired environmental conditions.
- Determine and select data requirements and display means.
- Verify system status from the System Control operator.
- Brief subjects and initiate exercise.
- Monitor and evaluate subject performance.
- Monitor aircraft system and navigational status.
- Insert special conditions during experiment.
- Modify scenarios or insert new parameter values or error tolerances.
- Freeze, reset, or back up exercise.
- Manually override preprogramed events.
- Monitor crew communications and serve as ground GCA.
- Operate special recording systems.
- Call up special data requirements on CRT.
- Terminate exercise and recycle system.
- Initiate data analyses, printout, and display.

The computer keyboard described earlier as part of the performance measurement subsystem will serve as the primary input and control device for the above functions. The overall controls required for this station are briefly summarized below. The first three items are in addition to those mentioned in the preceding section on performance measurement.

- Scenario control--Keyboard and other means to program and modify experimental scenarios.

- Environmental control--Illumination level, cloud cover, motion, vibration, noise, and crew station lighting.

- Experiment control--A major grouping of controls including switches, control-display indicators, and manual input devices for the structure and control of the experiment during an exercise, including such functions as start, halt, override, reset, and return to earlier phase.

- Keyboard--Computer interactive keyboard for major mission, experimental, and data control inputs.

  - CRT display terminal (alphanumeric) for use in conjunction with interactive computer keyboard,

  - Strip chart recorder,

  - Navigation controls and position plot,

  - Communication equipment (external and internal to cockpit),

  - Tape recorder,

  - Computer line printer,

  - Spare capacity measurement equipment,

  - CRT (for analog signals from biophysical measurements) and

  - Mission-time and time-of-day clock.

One important qualification must be made with respect to the above experimenter's controls. Depending upon the safety and complexity of operation, the setting of some initial conditions (e.g., velocity and illumination) may have to be under the control of the System Control Operator, described below.

One important feature of the controls will be their degree of automaticity. The following levels will be employed as appropriate.

- Automatic--e.g., data recording, reduction, and display

- Semiautomatic--e.g., instructor intervention of any automatic capabilities.

- Manual--e.g., establishment of initial and special conditions.

b. System Control Station. In addition to calibration, effective system operation and safety are of paramount concern. The VFRF will contain many complex and expensive subsystems which must be monitored for both system calibration and safety of operation. These include the visual stimulus mechanism, terrain table, transport mechanism, gantry, optical probe, TV chain, and crew stations. The probe, in particular, will be operating extremely close to the surface of the terrain table, and, unlike training exercises, flight maneuvers will be highly variable. As a result, the automatic safety of this system (among others) cannot be assured. For example, the drive systems must be monitored for speed and direction of motion. Control monitoring and safety interlock equipment, including the necessary mechanisms for the calibration of the visual display, must be provided for all electrical and mechanical systems.

The following basic requirements must be met by the system control station:

- System checkout and verification of operability;
- Alignment and calibration of all systems and displays, to established tolerances;
- Establishment of initial conditions where safety of operation and complex control requirements are involved;
- Monitoring of critical parameters during an experiment to assure safety of operation; and
- Fault isolation and location.

The system will be monitored from this station during the experiment. The system control operator will be an engineer who is mechanically and electrically oriented and will be responsible for the visual inspection of the total system, including the use of special aids, such as photometers, before system operation. The system control operator's functions are considered to be sufficiently important as to allow no other collateral duties. To avoid costly failures or accidents, this position will require full-time attention.

Examples of the types of control requirements for this station are as follows.

- CRT and computer keyboard--for test of selected signals relative to established tolerance levels;
- Display facilities for analog measurements (not covered by the above) required in the control and calibration process, including position and rate outputs for all drives, and selected signals from the TV chain;

- Control inputs for all sensor position and angle drives;
- Adjustment of windscreen display as presented on direct-view type TV monitors (located on flight monitor station), and other special displays (e.g., HUD);
- Repeater of special sensor displays and control adjustments (e.g., LLLTV and FLIR);
- TV monitor of all critical subsystems (e.g., gantry and transport mechanism);
- Controls for initial experimental conditions which, for safety of operation or calibration reasons, should be under control of this station, as well as the measurement control station (e.g., aircraft velocity, scene illumination). Redundant controls with safety interlocks or special features may also be used.
- A chart recorder, oscillograph, and test point panel for selected performance monitoring and fault isolation (including equipment running time clocks);
- Videotape recorder and controls for monitoring and playback of TV signals for documentation and troubleshooting;
- Lighting control panel with brightness and color temperature monitors;
- Motion base control panel with associated adjustments for six degrees of freedom, including variable gain;
- Atmosphere simulation control;
- Probe adjustment panel;
- Intercom with crew station;
- Status display board go/no-go, warning and malfunction lights, and safety interlocks;
- Power supplies and ancillary controls; and
- Mission freeze and emergency abort controls.

c. Flight Station Monitor. This station will have two primary functions:

- Monitoring the windscreen display and selected aircraft instruments, and
- Backup of pilot or copilot functions when needed.

The station will be designed so that both station operators can monitor the windscreen display and aircraft instruments (see Figure 18). Three or more CRTs will be used to present a repeat of the 120° FOV display in the primary cockpit. The system control operator will use these monitors, to the extent possible, to adjust and control the windscreen display with the controls provided. On the other hand, the experimenter will be provided with a continuous assessment of the real-world scene shown to the subject in the primary crew compartment. Cockpit instrument repeaters will be provided to permit a direct indication of aircraft flight status.

A simple control stick and throttle, for helicopter position, attitude, and velocity changes will also be provided to permit backup flight control. This mode of operation will only be needed when a subject or additional individual is not available to serve as a second crew member (i.e., a pilot). The experimenter will assume this function when necessary. In this respect, normal communication and navigation controls may be placed in or in juxtaposition to this station to further facilitate cockpit interface functions.

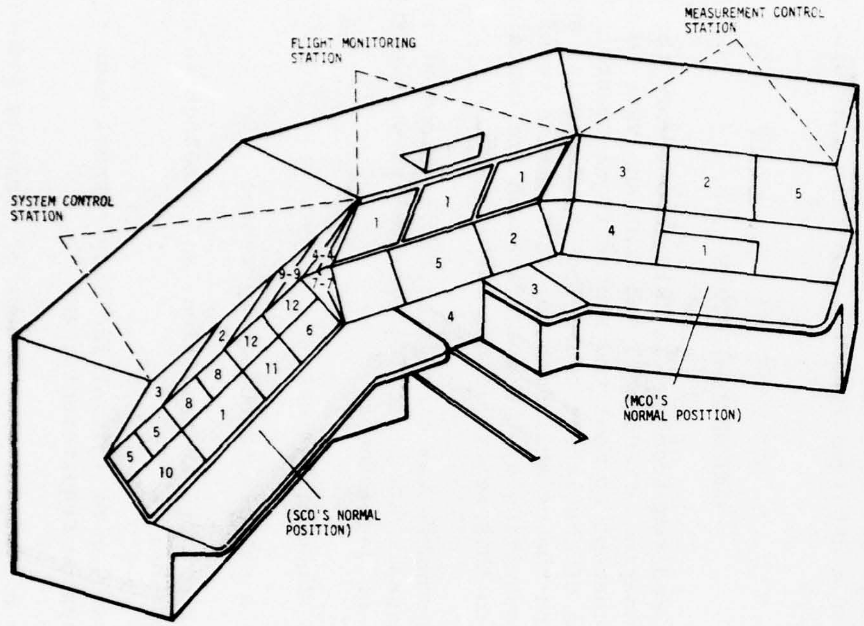
The final displays and controls and their layout in this station will be a function of a detailed function and task analysis, and human engineering principles.

CONCEPT SELECTION

The test goals and requirements in this report form the basis for the conduct of engineering, trade-off, and cost analyses to determine the optimum design concept to meet the stated requirements. This involves an evaluation of the latest technology to determine applicable design approaches and the establishment of performance requirements. These analyses and resulting system specification are contained in the companion document to this report (King, 1975).

A total system concept was considered for development in one or more procurement phases. The following constraints were established for the first phase of development.

- Lies within state of the art;
- Lies within a stipulated budgetary range;
- Permits fabrication, installation, and checkout in approximately 15 months;
- Permits expansion of initial facility capabilities to encompass the total system requirements; and
- Permits, as a minimum, the conduct of visually aided night NOE studies.



CONTROL/DISPLAY FUNCTION IDENTIFICATION

CONSOLE AREA	ITEM	FUNCTION
SYSTEM CONTROL STATION	1	KEYBOARD - COMPUTER INTERFACE
	2	CRT - COMPUTER INTERFACE
	3	MONITORING AND FAULT ISOLATING CRT
	4	LIGHTING CONTROL PANELS - WINDSCREEN AND E-O SENSOR
	5	PROBE CONTROL PANELS - WINDSCREEN AND E-O SENSOR
	6	MOTION SIMULATION CONTROL PANEL
	7	SYSTEM CALIBRATION CONTROL PANELS - WINDSCREEN AND E-O SENSOR
	8	TV CAMERA CONTROLS - WINDSCREEN AND E-O SENSOR
	9	SPECIAL EFFECTS SIMULATION CONTROL PANELS - WINDSCREEN AND E-O SENSOR
	10	TEST POINT PANEL
	11	CONTROLS AND SAFETY INTERLOCKS FOR DC POWER
	12	VIDEO TAPE RECORDER CONTROL PANEL
FLIGHT MONITOR-ING STATION	1	WINDSCREEN DISPLAY - 3 TV MONITOR ARRAY
	2	E-O SENSOR DISPLAY
	3	E-O SENSOR TRACK STICK
	4	FLIGHT CONTROLS (SIMPLIFIED)
	5	FLIGHT INSTRUMENTS (BASIC)
MEASURE-MENT CONTROL STATION	1	KEYBOARD - COMPUTER INTERFACE
	2	CRT - COMPUTER INTERFACE
	3	ANALOG CRT - BIOPHYSICAL MEASUREMENTS
	4	COMMUNICATIONS SIMULATION CONTROL PANEL
	5	INDICATORS (CLOCKS, RECORDING ETC.)

Figure 18. Test station control and display console configuration.

Concept Alternatives

Eight alternative simulation configurations were considered for evaluation and selection of the concept for the initial procurement. The configurations were basically compatible with one another, to permit growth from one another by means of additional equipment and with little or no modification to already existing equipment. The eight configurations differ with respect to combinations of the following basic capabilities.

1. Simulation of a day (color) and night capability or only a monochrome night capability.

2. Simulation of electro-optical sensors (e.g., FLIR and/or LLLTV) or the exclusion of this capability.

3. Provision of a wide FOV windscreen for both operators or for only one operator.

In the case of the latter option, a suitable CRT presentation would be provided for the second operator. Either the pilot or copilot would use the windscreen display, depending upon the objectives of the research study.

Each configuration has the following baseline capability: a minimum motion base, primary cockpit, test station, and wide-angle windscreen display. The alternatives are summarized in Table 9.

Concept Evaluation

The alternatives were evaluated with respect to cost, test capabilities that would be achieved, and state of the art. The most difficult requirements were resolution and illumination values for an effective day display that would meet psychophysical requirements. The requirements could be met, but only at a very high cost. As a result, a night display was elected, since the visual requirements were within the state of the art, as discussed previously, and because night NOE was the more difficult mode of flight operation. The elimination of a day-night capability (for the first phase, at least), appreciably reduced the range of potential tests that could be conducted.

The addition of a sensor capability (e.g., FLIR and LLLTV) represented the next important option which also had significant cost requirements. Whereas a day-night device without sensors would provide a significant test capability, a night device alone, without sensors, would have very limited utility. For this reason, a sensor capability was decided upon. This capability will permit determination of the pilot's basic visual capabilities at night and optimum sensor/display parameters for improved night vision.

Table 9

VFRF Option--Summary

Option	Image generation: "Windscreen" W-FOV color day/night	Image generation: "Windscreen" W-FOV monochrome night only	Image generation: E-O sensor aid N-FOV monochrome day/night	"Winterscreen" image display: Cockpit infinity matrix type, Single operator: Color day/night	Cockpit infinity matrix type, Single operator: Monochrome night only	Cockpit infinity matrix type, Two operators: Color day/night	Cockpit infinity matrix type, Two operators: Monochrome night only	Remote (direct-view) type TV monitors: Color day/night	Remote (direct-view) type TV monitors: Monochrome night only
A	X					X			
B	X		X	X				X	
C	X			X				X	
D		X	X		X				X
E		X			X				X
F		X	X				X		
G		X					X		
H	X		X			X			

The next major consideration was whether to provide windscreen displays for both operators. When two operators are seated side by side in a helicopter, the normal seating distance prevents the viewers from sharing a common infinity display (i.e., both simultaneously seeing the same wide FOV greater than 100°). Some alternatives are that each operator see 95°, with only a 54° common FOV in the middle, or that one see 120°, with the other seeing only 48°, which is common to both operators.

Two equivalent FOV displays for each crewmember are possible, if their seats are appreciably separated. This alternative was considered until it was determined that it would cost more, and even more significantly, would require an unusually wide cockpit. This led to the observation that one crewmember does not know what the other is seeing, being limited solely to verbal communication when seated side-by-side, or when the copilot is in the jump seat when an instructor is present. Conversations with helicopter pilots and military officers also confirmed this viewpoint. As a result, a large FOV windscreen display for one crewmember would be sufficient, with the other member viewing a TV presentation of the same scene, whether seated in the cockpit or elsewhere. This would permit coordinated flight functions, but not the accomplishment of realistic flight tasks simultaneously on the part of both operators. The pilot or copilot could alternately use the windscreen display, in such an arrangement, without any real loss in research capability, but at a significant cost savings.

Consideration was given to locating the second crewmember at the flight control station. The need for cockpit lighting control and the minimization of distractions led to the use of the secondary crew compartment. This compartment will be located adjacent to the primary cockpit. It will have CRT monitors of the windscreen display and a similar set of cockpit instruments. The control stick, however, will have simpler control functions. Either the pilot or copilot will use this compartment, depending upon the research objectives. If the pilot uses it, he will not be the primary objective of the study, and hence the control stick dynamics can be simpler. If a qualified pilot or copilot is not available, this station can be manned by a member of the test staff, or its functions can be handled by the experimenter at the flight control monitor, as described in the preceding section. It will also be possible for a third member of the test staff to use the flight monitor station itself, depending upon the work load of the experimenter and system control operator.

Concept Description

As mentioned previously, the primary flight compartment will be a research module where flight instruments and components can be readily changed. The secondary crew compartment will have a comparable capability. It will be located adjacent to the primary compartment but will be contained in its own enclosure to maintain the lighting integrity

of the primary compartment (from CRT glare, etc.). A G-seat motion and vibration system will not be included because of the secondary research goals of this station. Simulated cockpit noise, however, will be introduced via the earphones. Like the primary crew compartment, the secondary crew compartment will be monitored from the test station at the same level of detail.

As a result of the above considerations, the VFRF will consist of the following:

- A wide-angle, night visual display system of the external world, including cloud cover and lunar glare;
- A primary crew compartment incorporating the above display, helicopter controls, and instrumentation for one-man operation;
- A secondary crew compartment with CRT monitors of the windscreen display and simpler flight controls;
- Stimulus materials, sensors, and displays for the visible and simulated IR range (LLLTV and FLIR);
- Cockpit provisions and interface equipment for special devices such as helmet-mounted display, night vision goggles, and head-up display;
- A G-seat motion, noise, and vibration systems in the primary crew compartment;
- A comprehensive monitoring and control test station, including problem setup and initiation;
- High-caliber electronic and television subsystems to achieve the necessary quality and control of visual parameters;
- Cockpit provisions and a wide range of CRT sizes for display studies;
- Computer facilities for physical simulation, experimental control, data recording, and preprocessing;
- Ancillary research support equipment, such as video tape machines, photometers, radiometers, timers, special cameras, and display assessment devices.

A functional layout of the basic system components is shown in Figure 19. Specific performance characteristics are given in Appendix B.

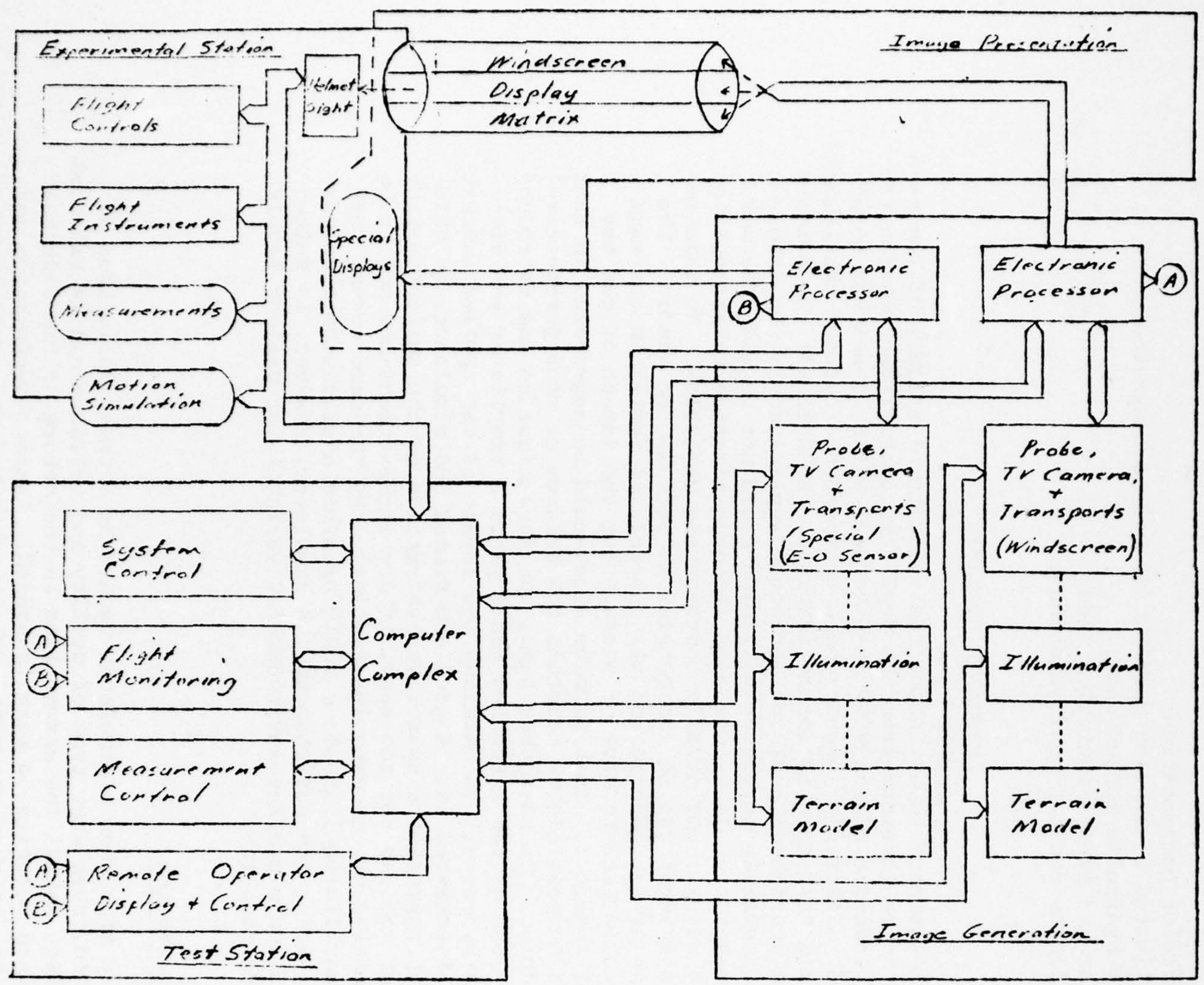


Figure 19. VFRF system diagram.

The primary growth items, if desired, that would remain as a result of the above concept would be as follows:

- Day/color presentation,
- Collimated windscreen display for second crewmember,
- 6 df hydraulic motion base,
- Solar and lunar simulation, and
- Alternate cockpit configurations.

RESEARCH UTILITY

It is legitimate to ask about the validity or utility of the research data to be obtained from the VFRF. Verisimilitude between the research environment of the VFRF and the real world is neither sought nor expected. Similarly, one-to-one correspondence between the laboratory and field test data is not anticipated. Even if all the primary environmental variables could be perfectly replicated in the laboratory, all potentially pertinent variables could not be (if they were known). Furthermore, it is not good research practice to attempt to simulate and use all potentially contributing variables. In this respect, an experiment can be too complex as well as too simple. The investigation or introduction of all possible variables in the same experiment would tend to mask or average out the impact of the key variables of interest. This problem also would be aggravated in that it would not be possible to maintain the balance or true perspective of the variables. On the other hand, the investigation and introduction of only one or two variables would yield a simplistic and distorted picture, as well as omitting the impact of the applied context that one is interested in. A good experiment and simulator, in this respect, must represent a selective abstraction of the salient variables, neither too few nor too many, if key interactions are not to be omitted or masked by too many interactions. By the same token, cost and technology limitations alone would prohibit a simulator from perfectly replicating the environment. A simulator, however, is suited to represent and mimic key environmental variables at various levels of simulation fidelity.

Data Characteristics

If it is true that a simulator cannot be a true replication of the real world, then what type of utility and validity can be expected of the research data? The answer lies in the nature of the data that can be obtained relative to what is needed. Perfect performance correspondence or "an absolute zero" relative to the real world is not possible. It will only be possible to measure distances or differences and not absolute magnitudes or their ratios. The limitation, however, is more apparent than real. In a research context, the following types of questions are paramount; fortunately they are highly amenable to the type of data that can be obtained.

- What is the direction or trend of the results?
- What is the magnitude of the difference between variable levels?
- What are the relative differences and ratio of improvement between systems?
- Are the data consistent for prediction purposes?
- What is the direction and magnitude of the interaction between variables?
- Can explanatory principles be determined?

It would still be desirable to obtain comparative or absolute estimations of real-world performance. These data, however, must be obtained by calibration and scaling to real-world results by means of field tests. To be successful, the field tests must be experimental in nature and highly controlled (including instrumentation and documentation of real-world conditions). If adequate tests are run, one would then be in a position to adjust or scale laboratory data for real-world predictions. Basic laboratory data and calibrated data would serve different purposes. For example, it could be predicted that display "A" will improve performance over display "B" by a certain percentage. Correspondingly, its level of performance in the real world could also be predicted.

Calibration of simulator data with the real world was conducted for the visual detection simulator (VDS) of the Federal Aviation Administration (FAA) located at the Transportation System Center, Cambridge, Mass. (Graham, 1974). The VDS consists of 28 slide projectors (35mm) working in 14 pairs. This combination of equipment apparently yields one arc min of resolution at about 300 FL of brightness. It was designed primarily for visual detection and tests of pilot warning instrumentation (PWI). Highly controlled tests were run in the field and in the VDS, with the same pilots and viewing conditions. Despite the high quality of the visual display, the simulated results were about 70% of the real-world data due to "limitations on the photographic fidelity (e.g., resolution, highlight luminances, field of view and noise) . . . ." (Graham, 1974). With some adjustment for differences in aircraft sizes, the data could also be transposed. The obtained differences were ". . . similar to the differences between real-world data and real-world data translated to a new visibility."

A different approach was used for the evaluation of the display fidelity of training simulators. It compared a pilot's effort in a simulator and in an aircraft with respect to the same task (Aronson, 1973). The approach recognizes that many evaluation techniques are not sufficiently sensitive to response variations due to visual cues.

Four variables, however, were identified and evaluated. These are elevator and aileron movement and the point of landing and the landing attitude at touchdown. While this approach will have more utility for a training than a research application, it illustrates another calibration technique (which assumes no error tolerance in the aerodynamic simulator).

Levels of Simulation Fidelity

Several levels of simulation fidelity can be described which influence a simulator's representation of the real world. These are physical, psychophysical, and psychological.

Physical Simulation. This level of simulation attempts to replicate all variables as precisely as possible. The aerodynamic simulation of aircraft performance is a representative example. Accuracy of 100% is usually sought, including the simulated effects and interactions of such factors as wind, barometric pressure, rough air, and icing. Similarly, the effects of fuel consumption on the aircraft's center of gravity and other internal aircraft state variables are taken into account. This level of simulation often attempts to replicate the fidelity of the internal system processes, in addition to the fidelity input/output processes. The latter is generally sufficient, since only they can have manifest influence on the student. This level of physical simulation or versimilitude is attempted in training simulators, despite the fact that the training requirements could be satisfied at a much lower level of fidelity or even with a different conceptual approach. The VFRF will have little, if any, true physical replication of the real world. A limited case will occur, however, in the simulation of aircraft noises through the pilot's headphones.

Psychophysical Simulation. Early psychological experiments have shown that subjects do not react in a one-to-one fashion to the physical environment. According to Fechner's law, "the sensation is proportioned to the logarithm of the stimulus" (Woodworth, 1950). In addition, there are stimulus thresholds for response and adaptation levels. For reasons such as these, human response ranges occur over relatively delimited physical stimulation ranges. For example, visual acuity levels off rapidly at about 100 FL, although in the real world, we are exposed to much higher light ranges (see Figure 12). As a result, high-brightness research can be conducted at the lower light levels, since the subjects' response would be essentially equivalent to that found at the higher light levels. Thus psychophysical equivalence in performance is sufficient rather than exact physical replication of the environment. This has been the guiding approach for both the visual and motion requirements of the VFRF. In the latter case, we have avoided the use of the latest highly complex motion systems which attempt to replicate the motion environment (even though

they also must rely on psychophysical principles to be effective) in favor of motion cues which will elicit responses comparable to those for the real world. The desired level of aerodynamic and instrument fidelity also falls into this realm.

Psychological Realism. Psychological realism refers to the fact that a person can perceive events which cannot be readily substantiated by the physical event itself. This occurs in such phenomena as apparent brightness, motion, size, shape, and color constancy (Gibson, 1966). Brightness constancy, a common example, can be experienced when viewing a movie. The viewer has the impression of watching a daylight or high-brightness scene when in fact the illumination of the screen is at twilight levels (e.g., 4 to 5 FL). The distinguishing difference from a psychophysical relationship is the fact that a subject's visual acuity will be less than the level that would occur under a higher or true brightness condition. Psychological realism could also be induced by random motion events, where operator responses would not be positively influenced. The proposed cockpit vibration system will fall in this category, where realism is sought without valid human performance effects. Face validity is another term that can be used for psychological validity.

Psychological validity plays an important role in establishing a realistic research context. This often is important to produce task loadings similar to those in real life. In this sense, the face validity of instruments and controls will establish the necessary context for the validity of the primary experimental variables which have been simulated at psychophysical levels.

A research simulator will need both types of simulation fidelity, i.e., psychophysical and psychological. The VFRF requirements have been established on this basis, with the psychophysical being the primary consideration. The research results should have validity and utility within this framework. Calibration with real-world conditions will also be sought. This will be made possible by the close association of this device with complementary field studies at Fort Rucker, as described earlier.

OTHER RESEARCH FACILITIES

Major Research Facilities

Several large military research facilities have either been completed, are under construction, or are being planned. They are as follows:

ASUPT: "Advanced Simulation Under Graduate Pilot Training." This unit is located at Williams Air Force Base, Ariz. It is designed to investigate both the effects of and interaction of simulation and training technology on pilot training. The system has been installed and is now undergoing preliminary testing.

SAAC: "Simulator for Air to Air Combat." This dual cockpit system is designed to simulate and evaluate air-to-air combat tactics and will be located at Luke Air Force Base, Ariz. The system has currently been completed and is undergoing checkout at Singer Simulation Products Division.

AWAVS: "Aviation Wide Angle Visual System." This unit, being procured by the Naval Training Equipment Center, was scheduled for completion by October 1976. It is designed for the investigation of visual and motion coupling and fidelity requirements for training, and performance assessment measures. A separate vertical takeoff and landing simulator will also be added.

EOSS: "Electro-Optical Simulation System." This facility is designed to support a broad range of E-O missile sensor system hardware and is located at the U.S. Army Missile Command, Redstone Arsenal, Ala. At present, plans are being formulated to add a crew cockpit simulator to interface with the EOSS.

The existence of these systems prompted the question as to whether VFRF requirements could be met by them, and the more basic or philosophical question as to whether the requirements of a highly specialized research facility such as the VFRF could be satisfied by a larger scale, "all-purpose" research facility. This latter question is raised in view of the propensity of some organizations to periodically promote such a system. The unique requirements of NOE flight and a night simulation capability precluded the satisfaction of these requirements in the above systems but still left the large and basic question open as to whether "all-purpose" systems could effectively meet highly specialized requirements.

Some individuals have argued for comprehensive, all-purpose simulation devices to permit complete interactions with all possible system variables and conditions, when in fact many variables can be held constant or not considered at all. These simulators generally become prohibitively expensive, with long development times. Their proponents usually find that many specialized problem areas (e.g., vision) cannot be adequately addressed due to the lack of definitive planning as well as the inherent inflexibility of the device itself. The following observations can be made in this regard.

1. The cost of an all-purpose system would be appreciably greater than a highly specialized device such as the VFRF. The costs of the systems mentioned above, for example, are about four to eight times higher than the estimated cost of the VFRF.

2. Procurement time would be much longer because of the increased system complexity and checkout requirements.

3. A conflict of priorities would occur, with different test objectives competing with each other; also, time would be lost in converting from one test goal to another.

4. There is evidence that many large systems tend to lack flexibility and, as a result, become limited to a very narrow range of research questions.

5. A general-purpose device may not have the necessary detail and flexibility to meet the highly specialized requirements of a unique problem area.

In view of the above, there is a basic incompatibility in the concept of an all-purpose, generalized device meeting the requirements of a highly specialized research facility. The breadth and complexity of the former would be incompatible with the detail and flexibility needed in the latter. The specialized tests could monopolize the time of the larger and more expensive system, when its goals could have been met more effectively with a less expensive, dedicated system. While an all-purpose system may be intuitively appealing, it will cost appreciably more for a highly reduced capability in any given area.

There are many other (large and small) research facilities throughout the country, in addition to those mentioned above. To adequately review the salient features and simulation technologies of these systems would require extensive effort, in view of the large number available. Fortunately, many reviews have been conducted of different systems and at different times. An excellent review was conducted by Hurd (1973) and Bailey (1974), each prior to and for the development of research simulation requirements for the FAA and the U.S. Army Missile Command, respectively. Valverde (1968) presents a general review of the research and development of flight simulators and related areas since 1949. Extensive trip reports also exist as a result of special agency reviews (Park, 1971). The following facilities represent only a small percentage of key installations that are worth reviewing:

- Redifon System-American Airlines, Dallas, Tex.
- Flight Dynamics Laboratory, Wright-Patterson AFB, Dayton, Ohio.
- Differential Maneuvering Simulator, NASA, Langley Research Center, Hampton, Va.
- Guidance Development Center, Martin Marietta, Orlando, Fla.
- NASA, Ames Research Center, Mountain View, Calif.
- NASA, Manned Spacecraft Center, Houston, Tex.
- Device 2F-90, Naval Air Station, Kingsville, Tex.

The above sources provided an excellent overview and source of information, and minimized the travel requirements of the present effort. Visits and contacts were made, however, to determine

- If the Army or other organization has an existing facility, or one in the process of construction, that would satisfy the VFRF requirements;

- If there are any specific plans and specifications for a research facility elsewhere which may satisfy the requirements of the VFRF;

- If VFRF requirements could be met by the adaptation of existing facilities or modification of current plans.

No positive information was uncovered with respect to the above questions.

In addition to the above objectives, visits or telephone contacts were made to

- Review applicable simulation technology,
- Discuss and acquire pertinent data,
- Coordinate planned research efforts, and
- Evaluate surplus simulation equipment.

The places and persons contacted or visited are listed in Appendix F.

Relevant Army Installations

Three Army activities, in particular, have associated research interests. These are the Night Vision Laboratory, Fort Belvoir, Va.; the Avionics Laboratory, Fort Monmouth, N.J., of the U.S. Army Electronics Command; and the Army Air Mobility R&D Laboratory, Ames Directorate, located at Ames Research Center, Moffet Field, Calif. The descriptions of the research facilities and plans of these activities, as described below, are not intended to be complete but only representative of the technologies employed or contemplated. As in any organization, such plans are liable to change with new thrusts and directions.

Avionics Laboratory. The Advanced Avionics System Technical Area was visited at the Avionics Laboratory. This technical area is responsible for the integration (including prototypes) of technology resulting from developments in other technical areas of the Avionics Laboratory. It is responsible for the tactical avionics system simulator (TASS), which is used as a tool for the evaluation and verification of concepts. The research aircraft for visual environment (RAVE) also falls under its cognizance. Simulated systems are used in the TASS and RAVE. TASS, developed approximately 10 years ago by Singer-Link, consists of the following basic components:

1. Terrain "Belt"--The belt moves in a vertical direction to provide longitudinal motion. At present, a 300:1 scale factor is used. The other five DOF are provided by a probe and gantry system. The probe has a 50° FOV and focus limitations within approximately 1/4 inch and 1-1/2 inches of the terrain model in the vertical and horizontal dimensions, respectively.

2. Visual Display--Studies are generally limited to CRT presentations. When a visual display of the external world is desired, one Farrand pancake window, mounted forward of the cockpit window, has been used (primarily due to weight limitations of the motion system). Color displays have not been used.

3. Motion--A Melpar "Melranic IV" system is used which provides 4 DOF in pitch, roll, yaw, and heave.

4. Computers--A hybrid system, which includes the following computers, is available.

   1- EAl 8400--digital (32 K memory)
   2- EAl 8800--analog
   4- EAl 321R--analog
   1- DDP 24--digital (for data reduction).

5. Cockpit--A UH-1H cockpit is mounted on the motion base, with almost full instrumentation. Helicopter flight equations have generally been obtained from the manufacturer and adapted to either a linear or full forces moment model.

6. Sensors--A Conrac RQA 21/C is currently used in conjunction with the Farrand 30-inch pancake windows. LLLTV (and haze) is simulated by adjusting the brightness of the TV monitor. FLIR is simulated by varying the contrast and brightness of the display.

At present, system integration and development efforts in the area of navigation displays for NOE flight are underway. Alternative navigation systems, and the relationship between map display and navigation system errors, are to be evaluated. The navigation displays will be used in conjunction with the copilot's view of the "external" world at NOE altitudes. A 2,000:1 terrain belt is being prepared with a simulated area of 15.8 km x 7.2 km. The nearest simulated approach to the model, relative to the capabilities of the optical probe, will be approximately 40 ft in altitude, with objects nearer than 240 ft out of focus. A 180° FOV is desired, due to the short slant ranges and wide FOV scanned by the copilot. This will be attempted by three Farrand pancake windows (and three TV projectors), placed in "angular" juxtaposition in front of a fixed-base cockpit. The display resolution

is not known. The goal, however, is to simulate terrain relief and not "trees and leaves." Since the probe is limited to a 50° FOV, it is hoped that the optics can be slewed by means of a head tracker to where the pilot is looking (area of interest display). Night-vision goggles will be used and will be stimulated directly by viewing the virtual imagery of the pancake windows.

AMRDL. The Ames Directorate of AMRDL shares the extensive simulation facilities of the NASA Ames Research Center. A fixed-base simulator is available for fixed wing and helicopter studies. In particular, it is used for simulation of night NOE, and has the following characteristics. Its primary display is a 20-inch CONRAC 525-line color TV tube. A large, two-element, lucite plastic lens is interposed between the color tube and the pilot. This lens both magnifies the color image, and lends the impression of infinity (true collimation is not achieved). A 40° horizontal and 36° vertical field of view is created by the lens. An existing 600:1 scale model is used (certain features of the model range between 300 and 600:1 scale). The helicopter flight equations are a modification of a standard basic aircraft flight program. It is a nonlinear model that includes cross-coupling terms and uses a disc representation of the rotor rather than a blade element approach. It requires a 64K core memory and is currently programed in an EAI 8400 computer. It is estimated that the model is at least one-half as complex as the programs used in training simulators. A stability augmentation system (SAS) is also available, to ease control problems of the pilot. The cockpit is relatively simple, with one seat.

A standard brightness TV tube is used with the terrain model. Light levels on the monitor are varied primarily by changing the TV gain, rather than changing the illumination on the model. The Redifon probe (Mark IV) can approach the model to within 1/16 inch, which at 600:1 scale is equivalent to 3 ft simulated altitude. The estimated brightness of the display is 10 to 14 FL. The apparent brightness for simulated day studies is reported to be too low, and for the night studies, too high. While most of the NASA engineers were noncommittal, the resolution of the display was estimated to be about 12 min of arc.

The NASA engineers are presently in the process of putting together a new simulator for NOE studies. A fixed-based "Huey" cockpit has already been put in place. A true virtual-image reflective window will be used. The system will be limited, however, to the existing Redifon gantry, probe, and TV chain. For example, the FOV will be 60°, with significantly less light at the viewed scene, due to significant light losses through the reflective optics.

AMRDL personnel mentioned that they may develop a comprehensive helicopter research simulator for a broad range of studies, and have apparently initiated planning to this effect. Its potential relationship to the comprehensive plans to expand the existing EOSS facility at MICOM had not yet been addressed.

Night Vision Laboratory. The Night Vision Laboratory is also planning a part task simulator to study FLIR problems at NOE altitudes by means of a simulated cockpit and CRT displays. A display of the "external world" is not planned. It is understood that a 40-ft x 50-ft terrain table is being built for this device at 400:1 scale factor. This laboratory is also addressing the problem of optical probe limitations (i.e., FOV and resolution) when in close interaction with a terrain table. This laboratory has also been conducting extensive helicopter field tests of FLIR and LLLTV sensors (Stich & Palmer, 1973). They also conducted acceptance tests of the OPTIC Aircraft (OTAS-PNVS-Tactically-Integrated-Cobra) that was described earlier in this report. This aircraft will be used as part of the attack Helicopter-Clear Night Defense Phase II Experiment being conducted by the Combat Developments Experimental Command, Fort Ord, Calif.

The above activities represent the primary agencies for coordination purposes with regard to the VFRF research goals. The VFRF is designed to be compatible with the types of sensors and visual aids being developed by ECOM and other developmental agencies. Close coordination will also assure the compatibility of the VFRF with the latest Army visual aids and long-range technological developments, which will serve as inputs to VFRF requirements and research programs. Consultation and mutual information exchange is also anticipated. The VFRF will also provide a test bed capability to support and supplement many of the current field tests. Simulation facilities are needed, to better define study requirements before field test implementation.

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APPENDIX A

STUDY REQUIREMENTS

1. Scope

    a. Requirements--relative to the range of studies specified
    b. Concepts--suggested and alternative approaches
    c. Specification--to enable direct fabrication

2. Requirements

    a. Visual

        (1) Resolution and FOV requirements implicit in the operating environment (e.g., visual angles, dynamic realism, and visual tracking capabilities)
        (2) Visual parameters critical to a visual research facility (e.g., brightness levels, contrast)
        (3) Visual geometry and viewing envelope for two-man operation

    b. Helicopter

        (1) Degree of flight dynamics
        (2) Fidelity of instrumentation
        (3) Degree of cockpit functions necessary for workload sharing (e.g., communication, navigation)

    c. Requirements for Research Flexibility

        (1) One or more probes
        (2) Multiple stimulus sources and probe compatibility (e.g., film, terrain model, combinations)
        (3) Interface requirements for special devices (e.g., Helmet Mounted Display)
        (4) VFR and IFR study capability
        (5) Cockpit functions for special studies (e.g., navigation aids)
        (6) Multiple wavelength sensors and illuminants
        (7) Atmosphere simulation capability (e.g., solar, haze)

    d. Monitoring and Control

        (1) Calibration control and procedures
        (2) Physical measurement of environment (e.g., photometer, radiometer)

(3) Performance measurement parameters

    (a) Eye position indicators, pupilometers, visual thresholds
    (b) Psychomotor, physiological, and stress
    (c) Flight performance (dynamic and procedural)

(4) Performance measurement techniques: camera, videotape, timers, tape recorders, movies, strip charts, CRTs
(5) Setup and manipulation of experimental variables (e.g., lightning, sun position, haze, flight profiles)

3. Concepts

a. Stimulus materials

(1) Type and combination
(2) Characteristics (e.g., detail, scale)
(3) Wavelength fidelity
(4) Degree of real-world replication (e.g., exact duplication of military base)

b. Sensors

(1) Type and combination (e.g., standard video, flying spot scanners, IR, stereo)
(2) Characteristics: fidelity, standard, or breadboard

c. Displays

(1) Type (direct view CRT, virtual image, CGI)
(2) Special displays: fire control, head-up display
(3) Display characteristics: eye relief, real-time, and stop motion
(4) Overlay or dual-purpose capability

d. Trade-Offs

(1) Effectiveness and cost
(2) Determination of priorities: dynamic vs. static, degree of realism, resolution, distortion, scene brightness, and two-man simultaneous scene perspective
(3) Reliability

e. Add-on

(1) Additional capabilities: cockpit motion, fire control
(2) Compatibility requirements
(3) Cost

4. Specification

a. Fabrication of device

(1) Complete specification--build to
(2) Acceptance requirements
(3) Site preparation (space, power)

b. Characteristics of device

(1) Tolerance, accuracies, and ranges of flight, visual, and electronic subsystems
(2) Calibration and procedures
(3) Maintenance and reliability requirements

c. Electronic subsystems

(1) Sound-to-noise ratio
(2) Bandwidth
(3) Dynamic range

d. Computer

(1) Hardware and software
(2) Interface requirements
(3) Data conversion and preprocessing

5. Other Considerations

a. Promotional materials

(1) Artist concepts
(2) Facility layout
(3) Visual research and simulation capabilities

b. Order of delivery
c. Consultants
d. Minimum-maximum costs

6. End Product

a. Report depicting requirements, concepts, and rationale
b. Specification
c. Cost, including add-ons

APPENDIX B

VFRF SYSTEM SUMMARY CHARACTERISTICS

1. Windscreen Visual Display System

   a. Terrain Model

      - Scale--600 to 1
      - Orientation--Horizontal or vertical (contractor option)
      - Size--Total area $\geq$1,600 ft^2

        - Max form factor--3 to 1
        - Max height (if vertical)--24 ft
        - With 3 to 1 form factor, size ≈ 24 x 66.5 ft
          Scaled size ≈ 4.4 km x 13 km

      - Terrain/Targets

        - Rolling, moderately hilly type terrain, including rivers, streams, variety of roads, houses, bridges, railroad tracks, small farm, plus typical small rural towns (three). Towns to include area-type lighting (e.g., house windows and parking areas).

        - Two types of terrain areas and tree distributions to be used--one typical of Fort Rucker, Ala., area, and one typical of Central Europe (approximately equal areas).

        - Variety of military vehicles

        - Electrical power poles

      - Coloring--Realistically colored
      - Typical NOE course length ≈ 20 km
      - Typical NOE flight time on model ≈ 15 minutes at average velocity of 40 knots

   b. Terrain Model Illumination

      - Type--Spectral output to provide reasonable match with TV camera sensor spectral response (to achieve illumination efficiency), while providing a displayed gray scale characteristic similar to that perceived by direct viewing of the real world under LLL conditions.

GENERAL NOTE: The windscreen display will be physically and functionally compatible with the operational conditions imposed by the future possible addition of a 6-DOF motion base.

- Illumination level on model--Determined by camera sensitivity and optical probe characteristics (≈ 100 ft-candles estimated).

- Light pulse frequency--Phased to produce 360 pulses/second (approximately).

c. Optical probe

- FOV--140° circular
- Effective focal length (EFL)--6.5±0.5mm
- Entrance pupil diam.--1 mm
- T number--T/10.5 (nominal)
- Primary image format--17-mm dia. for 140° FOV
- Focus range--1.4 inches to infinity
- Focus control--Dynamic as a function of simulated altitude and attitude
- Tilt focus correction--Schiempflug type
- Mapping--h = Fθ type
- Resolution across FOV at infinity focus

Semifield Angle	Angular Resolution (nominal)
0°	3 arc min
50°	4 arc min
65°	7 arc min

- Resolution at center of field vs. altitude

Altitude	Angular Resolution (nominal)
∞ to 35 mm	3 arc min
15 mm	5 arc min
6 mm	7 arc min

- MTF (object in plane of best focus, for visible spectral range of 400 to 700 nanometers)

  1 On-axis--70% of diffraction limit
  2 30° Off-axis--50% of diffraction limit

- Optical coupling--Probe primary objective will be re-imaged into the TV camera system via relay lenses. Use of field divider to share horizontal FOV among multiple TV cameras is allowable provided that field division is not accomplished in the straightahead position.

- Roll control excursion--Unlimited
- Pitch control excursion--+25°; -40°
- Yaw control excursion--Unlimited
- Servo static accuracy--6 arc minutes (for each attitude servo)
- Probe protection--To be provided by hardware techniques and software control)

d. TV Camera System

- Type sensor(s)--High-sensitivity type specified, such as a SIT; must be a developed, proven-type sensor of "broadcast quality," meeting premium (1st) level spurious signal specs
- Operating mode--Monochrome
- Configuration--Separate camera head, camera control unit remote from camera
- Frame rate/interlace--60 field/sec, 30 frame/sec, 2:1 "locked" interlace
- Total scan lines/frame--945 (nominal)
- Total instantaneous FOV--125° horizontal and 35° vertical (nominal)
- Raster aspect ratio--1:3.67 for a single sensor (nominal), 1:1.29 for 3-sensor configuration (nominal)
- Vertical resolution (nominal)--600 TV lines, center; 500 TV lines, corner
- Horizontal resolution (nominal)--For single sensor, 2,140 TV lines/raster width; for 3-sensor configuration, 770 TV lines/raster width (per camera)
- Lag--10% residual signal after 50 milliseconds (NOTE: Lower lag desired to minimize loss of resolution under dynamic conditions.)
- Sensitivity--Video S/N $\geq$ 35 dB to be achieved with approximately 100 ft cds model illumination and specified optical probe

e. Gantry/Servos/Transport

(1) Longitudinal and lateral (scaled values)

- Velocity--200 knots (max); 0.34 ft/sec (min)
- Positional accuracy--±5 ft (unslaved mode)

(2) Altitude (scaled values)

- Max. excursion--2,000 ft
- Velocity--4,000 ft/min (max); 0.06 ft/sec (min)
- Positional accuracy--±0.5 ft (unslaved mode)

(3) Slaved operating mode (two models)--Scaled values

- Longitudinal and Lateral--±5 ft relative positional error (max)
- Altitude--±2.5 ft relative positional error (max)

f. Special Effects

Following effects will be simulated, either by electronic, optical, mechanical, or a combination of these methods:

(1) Meteorological

- Visibility
- Haze and fog
- Overcast ceiling
- Horizon

(2) Sky background simulation--terrain model(s) only

g. Visual Display Subsystem Characteristics

- Display type--Collimated, virtual image type with mirror and beamsplitter

- Display image source(s)--26-inch (diagonal), high-resolution (≈ 1,500 TV line), monochrome TV monitor(s)

- Display configuration--Overlapping horizontal matrix of three collimated units. (NOTE: Central FOV (≃ 35°) shall be continuous, with overlapping seams at least 17.5° from the dead-ahead position.)

- Total displayed FOV--125° horizontal and 35° vertical (nominal)

- System resolution*--Approximately 8 arc min/TV line pair in central field

- Output highlight brightness--≥1 ft lambert (max); 10^{-5} ft lamberts (min); continuously variable

- Collimation--The final image will be collimated to a minimum distance of 40 ft.

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*These are total visual display system requirements.

- Contrast ratio--30 to 1 (min)

- System gamma*--Unity ±0.1

- Image distortion (without probe and TV camera)--<5% relative to picture height

- Image distortion (with probe and TV camera)*--<8% relative to picture height

- Viewing volume--≥1 ft dia sphere, centered at the observer eye centerline position

- Variation in output brightness*--Max variation of ±5% in contiguous areas and ±20% overall (achieved with TV camera(s)/ probe viewing a terrain model surface of uniform brightness)

2. Simulated E-O Sensor Visual Display System

a. Terrain Model

Model dimensions and target configurations (natural and manmade) are similar to the windscreen system terrain model. Some alteration of model coloration is likely to enhance the "signature" of certain natural features in a manner representative of the simulated LLL sensor(s). Also, special "active" target sources may be used to simulate additional sensor target enhancement characteristics (e.g., "hot" targets viewed by a FLIR system).

b. Terrain Model Illumination

- Type--Source characteristics will depend on unique sensor simulation techniques proposed by the contractor, including possible use of optical filtering to enhance and to suppress certain model features

- Illumination level on model--Determined by camera sensor subsystem sensitivity (in spectral regions of interest) and optical probe characteristics. Estimated at 500 ft candles (max)

- Light pulse frequency--Phased to produce approximately 360 pulses/sec

c. Optical Probe

- FOV--60° and 8° circular (selectable, with 1/4 sec changeover time)

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*These are total visual display system requirements.

- Effective focal length (EFL)--16±2 mm*
- Entrance pupil diameter--2.5 mm
- T number--T/10.5 (nominal)*
- Primary image format--17 mm dia for 60° FOV*
- Focus range--1.4 inches to infinity
- Focus control--Dynamic as a function of simulated altitude and attitude
- Mapping--$h = F\theta$ type*
- Resolution at center of field--1 arc min (nominal max)
- MTF (object in plane of best focus for the spectral region of 0.4 to 1.0 microns)

  1--On-axis--95% of diffraction limit
  2--30° off-axis--50% of diffraction limit

- Roll control excursion--Unlimited
- Pitch control excursion--$+40^{\circ}$; -60°
- Yaw control excursion--Unlimited
- Servo static accuracy--6 arc min (for each attitude servo)
- Probe protection--To be provided by hardware techniques and software control

d. TV Camera System

- Type sensor(s)--High sensitivity type specified with good near-IR response and high resolution (>1,000 TV lines). Possibly 1-1/2" or 2" vidicon plus S-20 type intensifier(s) (NOTE: Specific sensor is a contractor option.)

- Operating mode--Monochrome

- Configuration--Separate camera head; camera control unit remote from camera

- Frame rate/interlace--60 fields/sec, 30 frame/sec, 2:1 "locked" interlace

- Total scan lines/frame--Selectable; typical range from 175 to 1,225

- FOV--Selectable; 60° and 8° diagonal (determined by optical probe)

- Raster aspect ratio--Adjustable; typical range 1:1 to 1:2

- Vertical resolution--Determined by lines/frame selected

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*Interrelated parameters subject to tradeoff.

- Horizontal resolution--Maximum ≥1,000 TV lines. Lower resolution achieved as desired by limiting video bandwidth with selectable low-pass filters.

- Lag--10% residual signal after 50 msec (desired).

- Sensitivity--Sufficient when operating with specified probe to produce 35 dB video S/N with model illumination ≤500 ft candles.

e. Gantry/Servos/Transport

Same as for Windscreen Display System, except that the E-O sensor probe will be biased to ride a nominal 5 to 10 ft (scaled) above windscreen probe at and below treetop level to minimize probe protection problem.

f. Special Effects

Meteorological and sky background simulation effect, similar to those used with the windscreen display system, will be used. In addition, special processing techniques will be employed to modify the characteristics of the basic video signal from the TV sensor. These are expected to include

- Gamma changing,
- Noise insertion (calibrated levels),
- Scan beam at focusing,
- Signal clipping (black level and/or white level),
- Video bandwidth modification, and
- Signal polarity inversion.

g. Visual Display Subsystems

As noted previously, the direct-view-type monochrome TV monitor (size dependent on the particular flight compartment configuration) is the basic display device planned for use with the special E-O sensor system. Typical basic characteristics will include

- Resolution--1,500 TVL (nominal max) and

- Brightness--Normally operated at relatively low levels (≥2 foot lamberts max, continuously adjustable for optimum operator viewing in conjunction with lower windscreen display, brightness levels).

Interface provisions will be included for additional devices. These include:

- Helmet-mounted display
- Head-up display.

APPENDIX C

VISUAL CUE ANALYSIS--PARAMETERS

An analysis will be conducted in helicopters during NOE flight to analyze and delineate the parameters of the dynamic visual scene. Information will also be obtained on the motion characteristics of the cabin, and noise levels. This information will be used primarily to help determine the visual requirements of the NOE Visual Flight Research Facility.

1. Visual Parameters

- Visual viewing range--minimum and maximum levels
- Visual angle subtended on the eye by prominent objects within the immediate line of sight
- Angular velocities of the viewed scene during representative helicopter maneuvers and speeds
- Nearest approach to trees along the three primary axes of flight
- Average height of the helicopter over the ground
- The relationships of the helicopter rotor to the trees, e.g., between, above, inclined. The average height of the helicopter above or below trees in these positions.
- Pilot's field of view horizontally and vertically, and percentage of time in delimited zones
- Average scene luminance during various flight maneuvers among trees and different sun positions (including average cabin luminance)
- The contrast relationship of trees to one another, to the general horizon and the ground
- The impact of various sun inclinations and angles to the cockpit, plus the degree and type of glare.
- The degree of haze attenuation at various viewing ranges
- Terrain characteristics--size, width, and girth of trees. Type of foliage and seasonal variation.

2. Pilot Visual Problems

The following type of information will be elicited by interview and/or questionnaire.

- Cues utilized for depth perception
- Visual illusions if any during particular flight profiles
- Experience of disorientation
- Effects of fatigue and "visual streaming" (e.g., loss of resolution)
- Visual scanning techniques and maintenance of orientation when viewing cockpit and transitioning to the outside world
- Visual cues used to aid the avoidance of obstacles
- Visual cues for pilotage
- Effects of sun glare
- Ability to differentiate trees (contrast) during seasonal variations
- Capability to perceive detail during normal flight and while visually tracking an object
- Distortions and problems introduced by the windscreen and during rain

3. Motion Parameters

Cockpit motions will be investigated with respect to pitch, roll, yaw, lateral, vertical, and longitudinal variations. To the extent possible, these degrees of freedom will be evaluated with respect to rate of onset, acceleration, rate of change, extent of change, frequency of change, and vibration. The pilot's perception of these motions during their corresponding maneuvers will also be assessed.

4. Cockpit Noise Levels

The average acoustical level of cockpit noise will be assessed as attenuated by the pilot's helmet and head set.

5. Instrumentation

While preliminary, the following types of instrumentation may be utilized in the planned analyses.

- Movie camera
- Videotape
- Still camera
- Laser rangefinder
- Light meter
- Gray scale devices
- Accelerometer
- Audiometer
- Timers.

APPENDIX D

VISUAL RESOLUTION OF THE WINDSCREEN DISPLAY

Prepared by J. Ohmart, Martin Marietta Corporation

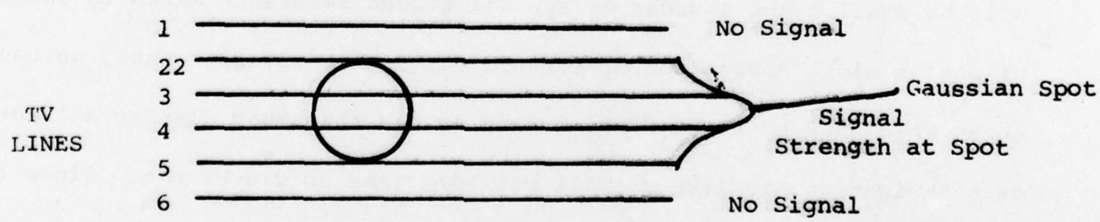
The statement has been made that the Martin Marietta Monochromatic Visual Display has a system resolution (not including the eyeball) of 8 arc minutes for a TV line pair, and that this gives an effective display resolution of 5 arc minutes. In reviewing the literature to find justification for the 5 arc minute number, it seemed that very little was available except for the material found in the excellent engineering reference source "Perception of Displayed Information" edited by L. C. Biberman. In the chart on page 4 taken from John Johnson's classic paper of 1958, it shows that for detection, targets often subtended less than a TV line pair; i.e., truck 0.90, M-48 tank 0.75, Stalin tank 0.75. Using this data, one could conclude that given a TV system with a resolution of 8 arc minutes per TV line pair, that system could display a target of 8 arc minutes x 0.75 or 6 arc minutes. However, in Johnson's paper he was taking psychophysical data in the most classic sense and the eye was the determiner of the resolution of the system. The test plan was not really directly applicable to arriving at the ultimate in TV system resolution as it relates to night NOE simulated flight projected by Martin for the ARI Research Facility.

In the NOE case, some of the most important ground details to be displayed will be small light sources or special ground reference marks to assist the pilots in night navigation or forward staging maneuvers. Thus, we can now talk about what happens to an 8 arc minute system that must display a light source or a navigation aid like a small pot hole lake or gravel pit. Since the literature search did not seem to produce exactly what was wanted for this justification, several experiments conducted at Martin are cited to help establish the 5 arc minute resolution as a conservative number.

In the first experiment (see Chart I) a TV camera was aimed at a small bright source and adjusted to discharge (no blooming) when the spot size was

3 lines at 15 volts vidicon target voltage as shown in Chart I. The spot was made progressively smaller and as it shows, the signal level dropped as did the spot size on the display until it was 1 line; below 1 line in theoretical size the spot continued to appear but grow dimmer as it grew smaller. Thus, a spot of a size smaller than one TV line still produced a one TV line image. No visual checks were made of this experiment, as it was all done by electrical recording.

A second experiment was based on the specific data needed for this justification. A 1000 ft L circle was placed at such a distance that it produced a spot two TV line pairs (or 4 lines--in this case equivalent to 16 arc min.) in size when the focusing zoom lens was set at the long focal length (250 mm). The spot size was checked electrically by using a line select oscilloscope to tell exactly in what lines the spot showed a voltage. The set up produced no signal in the lines above and below the four lines showing voltage changes representing the spot.



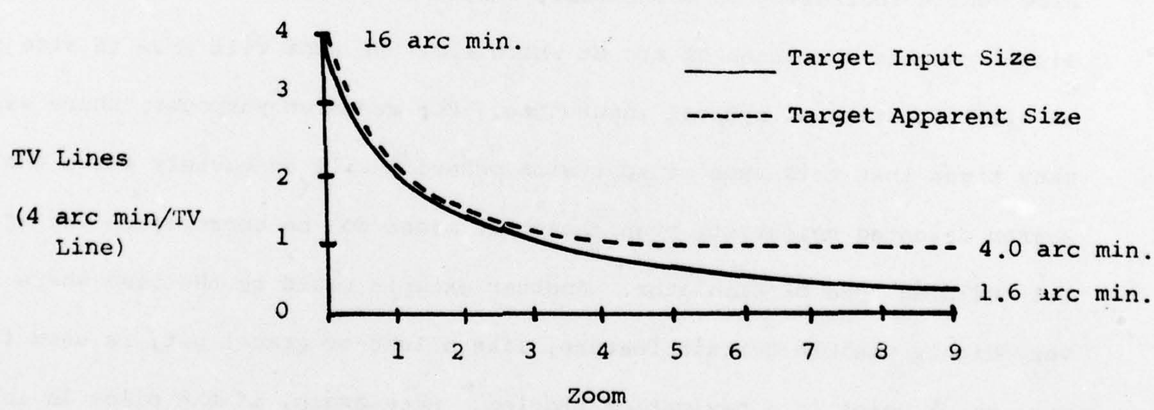
This configuration was confirmed visually by observing the high resolution monitor with a magnifying glass. At this time, the lens was zoomed to its

shortest focal length, which now makes the 16 arc minute spot 1.6 arc minutes of input to the system. In observing the new spot size on the monitor, it was much reduced in brightness and visually appeared to be one line wide. Electrically the signal appeared to come from one line, thusly:

	1	————————	NO signal
TV Lines	2	————————	SPOT signal
	3	————————	NO signal

It can be seen that the TV system will display an optically input spot size of 1.6 arc minutes as 1 TV line or 4 arc minutes. The natural extension of this experiment was to then slowly bring the zoom back to a 4:1 position observing the spot both visually and electrically. It grew in brightness but not in size until the zoom ratio exceeded the 4:1 reduction, at which time the spot continued to increase in brightness and now started to grow in size until it finally reached 16 arc min. or 4 TV lines, as shown on the following graph.

Visually apparent size of target with zoom



Desiring to be conservative in the spec, it was felt that while a 4 arc minute target could be resolved on a perfectly tuned system, it would be better to be more practical by assuming that the system would always lack perfection

in tuning and the Gaussian shape of the spot energy plot would tend to give a small overlap on each line, so 5 arc minutes was used.

The next question is, "Is it usable?" and the answer most certainly has to be "Yes". Several examples are given.

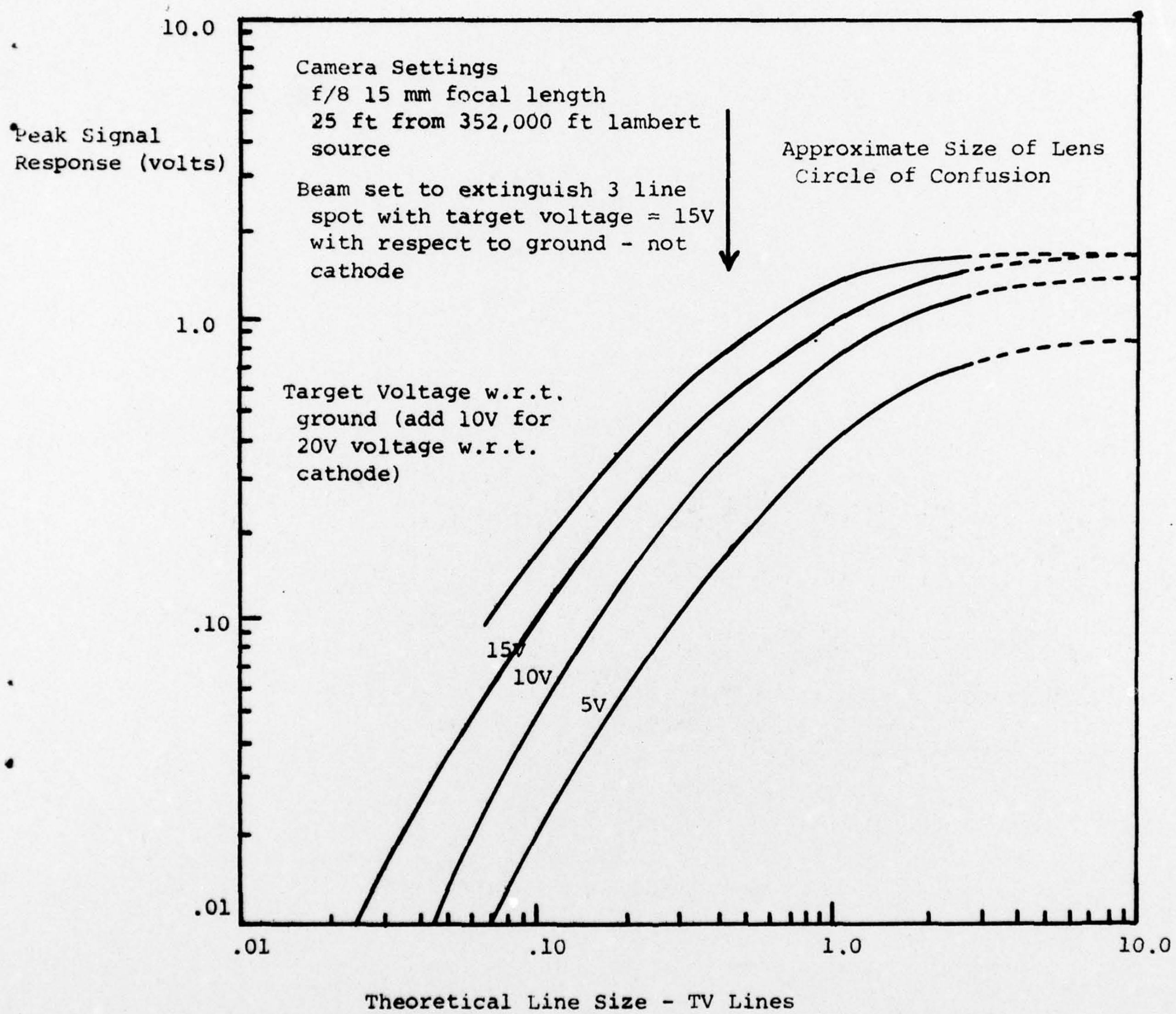
Let's take the case of a forward area staging signal. It is a light source that in the simulator will be a point of light produced by a single optical fibre, and seen by the optics of the simulator as much less than 1 min of arc at the predicted detection range. However, the display can only show a 4 (5) arc minute spot so the light will appear on the monitor, but will, in fact, be too large when first detected by the approaching helicopter pilot. (Previously in this paper, it has been shown that for 75 percent or more of the planned brightness levels to be used in the VFRF, the eye will be limited in its ability to see spots smaller than 5 arc minutes anyway at low contrast, to producing a 1 or 2 arc minute spot would not be of any real value. However, as the helicopter flies toward the light source, the displayed light will remain the same size (while increasing in brightness) until such time as the optical input signal exceeds 4 minutes of arc at which time the spot will grow in size directly as a 1:1 function of optical input size. For research purposes, there will be many times that this type of spot size behavior will adequately serve the research oriented scientist, even though it might not be appropriate for an exact 1:1 training type of simulator. Another example would be the case where some very highly visible terrain feature, like a lake or gravel pit, is used for some check point in a navigation problem. Here again, if the pilot is looking for this particular high contrast feature, he may be satisfied with the displayed 4 (5) arc minute feature, if it is correctly located on his chart.

Thus, a TV system that has the ability to resolve 8 arc min/TV line pairs should be able to resolve high contrast targets of something less than John

Johnson's 6 minutes of arc and something more than the theoretical limit of 4 minutes of arc. 5 arc minutes was chosen as a safe and dependable number.

CHART I

APERTURE EFFECTS ON SMALL SPOTS



APPENDIX E

COMPARATIVE EFFECTIVENESS MEASURES

Prepared by A. Siegel, Applied Psychological Services, Inc.

This attachment specifies the general approach and data reduction procedures to be used in calculating effectiveness for simulated missions (or phases within missions) as part of post flight data processing. Two independent measures are defined.

The first, called General System Effectiveness (GSE), will be a score which compares the overall performance of one man-machine system on its accomplishment of basic mission objectives (or phase objectives) against another such system. The GSE value will be based upon the five score categories in Table E-1.

Table E-1

Score Categories Comprising General System Effectiveness

GSE score category number	GSE score category	Notes
1	Flight quality	Smoothness
2	Flight accuracy	Actual vs. nominal
3	Pilot effort exerted	Related to physical fatigue
4	Pilot biophysical reaction	Related to mental stress
5	Accomplishment of mission objectives	Mission oriented goals

All items have been selected so that a smaller score indicates a superior system.

The first category, flight quality, provides a measure of system output. A man-machine system which provides for a smoother flight is superior in this category. The eight items which are selected for scoring are shown in Table E-2 together with the score nomenclature, N_{kji},

where k is the item number,

j is the number of the system being scored, and

i is the score category (i = 1 in this case).

The second category is based on measures of the closeness of the simulated flight to that of a preselected nominal flight path. Whatever the mission, the system which enables the pilot to perform his mission with precision is preferable to the one which causes a greater deviation from the ideal. The items which comprise score category 2 are given in Table E-3.

The third category (i = 3) is based on measures of the pilot effort exerted during the mission. These are numbers of recorded movements of major controls, as shown in Table E-4.

The fourth category involves the biophysical data and represents pilot stress, as shown in Table E-5.

The last GSE score category (i = 5), as shown in Table E-6, measures the level of success achieved in accomplishing specific mission (or phase) objectives.

Calculation of General System Effectiveness

Assume now that N_{kji} data are taken and averaged on an autopilot simulation run with a nominal flight plan for all k items in each of the i score categories discussed. The same is then done for a man-machine system to be evaluated. The primary technique for evaluation, then, consists in calculating a merit rating:

$$X_{ij} = \sum_k d_{ki} e^{-(N_{kji}/N^*_{kji} - 1)}$$

For each system, j, and score category, i, d_{ki} is a weighting factor which reflects the relative importance of the k items in the i score categories. The weights are such that $\Sigma d_{ki} = 1$ for each i; e is the natural logarithm base. The symbol N^*_{kji} is defined to be the smallest of the N_{kji} values for the two systems being compared. This allows a simulation run to be compared against a nominal or any two runs to be compared against each other.

Table E-2

Items in GSE Score Category 1-Flight Quality

Item no. k	Item	Score N_{kji}
1	Count of pitch threshold crossings	N_{1j1}
2	Count of roll threshold crossings	N_{2j1}
3	Count of heading threshold crossings	N_{3j1}
4	Count of airspeed threshold crossings	N_{4j1}
5	RMS deviation from nominal for rotor RPM	N_{5j1}
6	RMS deviation from nominal for engine RPM	N_{6j1}
7	Total of control column displacement	N_{7j1}
8	Total of rudder column displacement	N_{8j1}

Table E-3

Items in GSE Score Category 2-Flight Accuracy

Item no. k	Item	Score
1	Integrated deviation from nominal in position	N_{1j2}
2	Integrated deviation from nominal in heading	N_{2j2}
3	Integrated deviation from nominal in airspeed	N_{3j2}
4	Number of movements in wrong direction-pitch	N_{4j2}
5	Number of movements in wrong direction-roll	N_{5j2}
6	Number of movements in wrong direction-heading	N_{6j2}
7	Number of movements in wrong direction-airspeed	N_{7j2}
8	Percent distance traveled off course, i.e., outside the tolerance band	N_{8j2}

Table E-4

Items in GSE Score Category 3-Effort Exerted

Item no. k	Item	Score
1	Number of control movements (pitch)	N_{1j3}
2	Number of control movements (cyclic control stick)	N_{2j3}
3	Number of control movements (rudder pedals)	N_{3j3}
4	Number of control movements (throttle, power control)	N_{4j3}

Table E-5

Items in Category 4-Stress

Item no. k	Item	Score
1	Heart rate	N_{1j4}
2	Blood pressure systolic	N_{2j4}
3	Blood pressure diastolic	N_{3j4}
4	Skin resistance	N_{4j4}
5	Breathing rate	N_{5j4}

Table E-6

Items in GSE Score Category 5-Accomplishment of Mission Objectives

Item no. k	Item	Score
1-6	Object detection threshold times (difference nominal-actual)	N_{1j5} to N_{6j5}
7-12	Object detection threshold failure/ success and failure	N_{7j5} to N_{12j5}
13-18	Object recognition threshold times (difference nominal-actual)	N_{13j5} to N_{18j5}
19-24	Object recognition threshold times success/failure	N_{19j5} to N_{24j5}
25-30	Differences between actual and nominal altitudes at object recognition times	N_{25j5} to N_{30j5}
31-36	Differences between actual and nominal airspeeds at object recognition times	N_{31j5} to N_{36j5}
37-42	Test conductor's assigned scores on critical tasks	N_{37j5} to N_{42j5}

For illustration, an example is shown in Table E-7. (No relation exists between the magnitude of these illustrative data and the specific items or score categories.) Here, four score categories (column 1) and a total of 17 items (column 2) are used. The scores resulting from measurements of one system against the nominal or of two systems to be compared are given in column 3. Note that the scores cover a wide range of values as may be expected from monitoring such a variety of parameters. The item weights, d_{ik}, (arbitrarily selected in this case) are given in column 4; note that the sum of the item weights for each score category equals unity. The smaller of the two N_{kji} items in each row is shown in column 5 as N^*_{kji}. The value of N_{kji}/N^*_{kji} is shown in column 6 and will always be unity for the system having the lower (better) score on that item; the other value is greater than unity. The value of $e^{-(N_{kji}/N^*_{kji} - 1)}$ is given in column 7. The best possible value here is unity, the worst zero. The product of these data by their respective weights (d_{ki}) is shown in column 8 for each system. The total of the values of column 8 represents for each system the merit rating X_{ij}, shown in column 9. Values of X_{ij} will range between unity (best) to zero (worst). The index of merit, M_j, is computed for each system according to the formula:

$$M_j = \sum_i c_i e^{X_{ij}}$$

Table E-7

Hypothetical Example of Effectiveness Measure Calculation

(1)	(2)	(3)		(4)	(5)	(6) = (3)/(5)		(7)		(8)		(9) = $\sum_k$(8)		(10)	(11)		(12) = (10)x(11)		(13)
Score Category i	Item Number k	Score System 1 (N_{k1i})	Score System 2 (N_{k2i})	Item Weights (d_{ki})	Smaller N_{kji} (N^*_{kji})	N_{kji}/N^*_{kji} System 1 $j = 1$	System 2 $j = 2$	$e^{-(N_{kji}/N^*_{kji} - 1)}$ $j = 1$	$j = 2$	(4) x (7) $j = 1$	$j = 2$	Merit Rating X_{ij} $j = 1$	$j = 2$	Score Category Weights c_i	$e^{X_{ij}}$ $j = 1$	$j = 2$	$c_i\ e^{X_{ij}}$ $j = 1$	$j = 2$	Merit Ratio $R = M_1/M_2$
	1	180	165	.20	165	1.09	1.00	0.91	1.00	.182	.200								
	2	172	163	.25	163	1.06	1.00	0.94	1.00	.235	.250								
1	3	2440	2500	.15	2440	1.00	1.02	1.00	0.98	.150	.147	.939	.997	.25	2.558	2.710	.639	.678	
	4	1350	1210	.10	1210	1.12	1.00	0.87	1.00	.087	.100								
	5	2110	2000	.30	2000	1.05	1.00	0.95	1.00	.285	.300								
	1	420	451	.15	420	1.00	1.07	1.00	0.93	.150	.140								
	2	35	30	.15	25	1.17	1.00	0.84	1.00	.126	.150								
2	3	3.1	3.2	.15	3.1	1.00	1.03	1.00	0.97	.150	.146	.976	.863	.30	2.654	2.370	.796	.711	
	4	29	38	.20	29	1.00	1.31	1.00	0.73	.200	.146								
	5	50	60	.20	51	1.00	1.20	1.00	0.82	.200	.164								$\frac{2.64}{2.48} = 1.06$
	6	52	65	.15	52	1.00	1.25	1.00	0.78	.150	.117								
3	1	6.4	7.1	.55	6.4	1.00	1.11	1.00	0.90	.550	.495	1.000	.887	.20	2.718	2.428	.543	.486	
	2	420	480	.45	420	1.00	1.14	1.00	0.87	.450	.392								
	1	6	8	.25	6	1.00	1.33	1.00	0.72	.250	.180								
	2	0.1	0.1	.25	0.1	1.00	1.00	1.00	1.00	.250	.250								
4	3	5	6	.25	5	1.00	1.20	1.00	0,82	.250	.205	.975	.885	.25	2.651	2.423	.663	.606	
	4	10	9	.25	9	1.11	1.00	0.90	1.00	.225	.250								
													Total	1.00	Index of Merit $M_j = \sum_i c_i \cdot e^{X_{ij}}$		2.641	2.481	

The number of score categories, items, and scores in this chart has been selected only for illustrative purposes.

where c_i are weighting factors giving the relative importance of the i score categories for the mission under consideration, such that $\sum_i c_i = 1$ (see column 10).

The intermediate values of $e^{X_{ij}}$ are shown in column 11, and their respective products with c_i are given in column 12. The totals at the bottom of column 12 are the indices of merit for the two hypothetical systems.

$$\text{system 1:} \quad M_1 = 2.641$$

$$\text{system 2:} \quad M_2 = 2.481$$

In general, the value of M_j is limited to the range from the natural logarithm base e (best) to unity (worst). Thus, in this case, system 1 is superior.

A merit ratio $R = M_1/M_2$ may be calculated. In the example, this value is 1.065. This value indicates a ratio of superiority in favor of system 1 of about 6.5%.

The program will allow both calculation on the basis of phase data as well as total mission data. The phase calculation routine will print, as final output, the M_j data by phase.

The second approach to the evaluation of a man-machine system on a given simulated mission is the generation of a computer listing of additional results. Principally, it is a collection of collateral effects and is therefore termed Collateral Systems Effectiveness (CSE). The data are described in Table E-8.

Table E-8

Collateral Systems Effectiveness Data

Item no.	Item	Notes
1	Spare capacity a. percentage correct responses b. average response times	Measures capability to perform additional work
2	Eye movements a. average time in each grid section b. difference of two matrices	Measures extent of visual acuity
3	Communications see Section 2.1., Siegel and Federman, 1973	Team integration
4	Cortical evoked response a. mean sigma and quartile deviation for amplitude and latency of cortical response	Experimental measure

APPENDIX F

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